MONITORING UNDERGROUND CABLE CONDITION UTILIZING THIRD HARMONIC CURRENT

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Department of Electrical & Electronic Engineering
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

Approved:

_____

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TRONOH, PERAK

January 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

_____

MOHD ASNAWI BIN MOHD YUSOF

ABSTRACT

Power failure in a power system caused by unscheduled cable failure may give significant problem to the utility company and to the consumers. This unscheduled cable failure can be overcame by periodically monitor the cable condition. There are many ways to monitor cable condition such as visual inspection, infrared thermography, ultrasound, insulation resistance and others. Third harmonic in triplen harmonics may also be used to monitor cable condition. Lab experiments have been conducted to investigate the relationship of third harmonic voltage and current passing various cable conditions that specifically affected by their insulation. The objective of this research is to study the applicability of using third harmonic to monitor cable condition. Preliminary research is done to collect necessity information and vigorous lab with different loads is initiated to achieve the objective. Further discussion is made to come out with a conclusion of the project and recommended steps are listed for future development. The results show a significant existence of third harmonic voltage and current at the phase line and the value at the neutral line is three times from the phase line. Connection of transformer (delta-wye) will only circulate the third harmonic current at delta connection from flowing continuously into the wye connection and the load. The third harmonic flows through a capacitor significantly at a range value of 1uF to 2uF.

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CHAPTER 1 PROJECT BACKGROUND

1.1 Background Study

Harmonic is defines as a sinusoidal component of a periodic wave or quantity having a frequency that is an integral of the fundamental frequency as stated in IEEE Standard Dictionary of Electrical and Electronic Terms, IEEE Standard 100, 1984. Harmonics consist of odd and even harmonics. In an electrical system, the even harmonics do not give any significant effect to the signal thus can be neglected. Triplen harmonics currents and voltages are the odd multiples of third harmonic (3rd, 9th, 15th, etc). Third harmonic current has been observed to flow through cable insulation with the existence of water tree.

1.2 Problem Statement

Unscheduled insulation failure in power cable may give unwanted surprise that could result in power failure and system breakdown. Early detection of the problem by monitoring the cable condition may help the utility to supply a continuous power supply to meet the people's demand.

1.3 Objectives

The weakness of the third harmonic current that flows through the insulation of cable may be used as an advantage to monitor deteriorating of cable insulation. The third harmonic current that flows back to the generator through the cable insulation of the power cable may be emulated by using capacitor as the cable insulation. Data from lab experiment will be analyzed to determine third harmonic signature for various cable insulation conditions.

The objectives of the project are:

1. To study the behavior of third harmonic voltage and current when under various cable insulation conditions.
2. To study the applicability of third harmonic in monitoring underground power cable.

1.4 Scope of Study

The project starts by studying the underground power cable structure and the function of its components for commonly used power cable such as cross-linked poly-ethylene (XLPE) and paper insulated lead covered (PILC) cable. The position of power cable used is also important whether it is underground cable or overhead line cable. Not only that, by studying the power cable and its components, the cable capacitance can be identified which act as the insulation of power cable.

Then, the methods of monitoring cable condition are identified and studied. There are several methods that can be looked on such as visual inspection, infrared thermography, ultrasound, insulation resistance, dielectric dissipation factor and partial discharge.

Harmonics are then to be understood deeply. How harmonics flow in a power system, how it exists and what are the levels of harmonics can be researched to have a good understanding.

Last but not least, vigorous lab experiment will be conducted to investigate the relationship between cable capacitance or cable insulation and the third harmonic behavior.

CHAPTER 2 LITERATURE REVIEW

2.1 Underground Power Cable

Power cables are used for transmission of electrical power. Cross-linked poly-ethylene (XLPE) cable is one of the most popular types used nowadays for medium voltage cable. This type of cable has generally used to replace the paper insulated lead covered (PILC) cable [1]. Even though XLPE cable has a lifespan of more than 20 years, but due to overheating and moisture ingress, it makes the cable to have a shorter lifespan than it should be [1,2]. Moisture ingress or water tree that is penetrated into the insulation can also causes the cable to degrade [3]. Figure 1 shows the cross-section of XLPE cable.

Nexans, a cable experts company details the function of each layer of an underground cable. A conductor conducts the electricity in the cable. The conductor screen maintains a uniform electric field and minimizes electrostatic stresses. XLPE insulation functions as a thermosetting that is very useful for high temperature applications. Insulation screen has similar function as the conductor screen. Copper tape screen is used as a shield to keep electromagnetic radiation in and also provides a path for fault and leakage currents. The filler acts as a filling component to the empty spaces inside the cable. Binder tape and PVC bedding keeps the bundle together and provides bedding for the cable armor. Galvanized steel wire armor protects the conductor bundle from any mechanical damages. Lastly, the outer sheath is applied over the armor for overall protection of mechanical, weather, chemical and electrical damages.

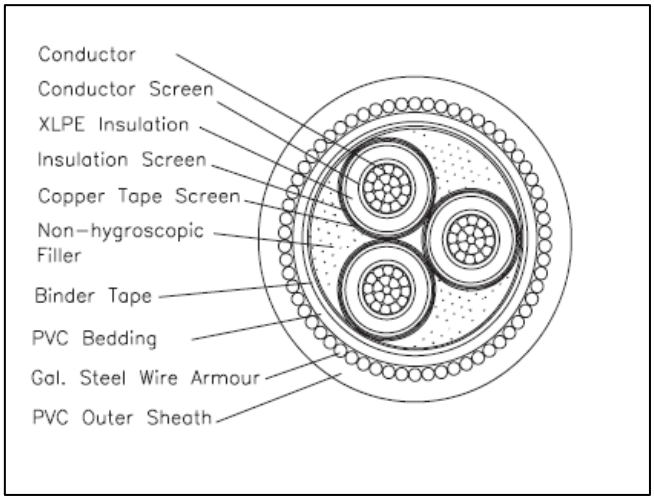

Figure 1: Cross-section of XLPE cable

2.2 Condition Monitoring of Underground Power Cable

Based on the research in [1], condition monitoring of cables are very important because it enables the related utility company to carry out precaution step to overcome any failure. Some of the common monitoring ways are visual inspection, infrared thermography, ultrasound, insulation resistance, dielectric dissipation factor and partial discharge.

Based on [2], cross-linked poly-ethylene (XLPE) cable replaces paper insulated lead covered (PILC) cable. Some of the factors for cable failures are overheating and moisture ingress. Visual inspection is mainly at termination terminal of transformer and switchgear. Infrared thermography is done by checking signs of overheating at termination terminal, and this may detect degradation of cable. Ultrasound works by detecting noise at the cable termination terminal. Insulation resistance is one of the most traditional ways to monitor cable condition by applying voltage to the insulator and detect the ratio of the voltage to decide the condition of the cable. Dielectric dissipation factor is when a higher loss factor can be detected when the cable is damaged by the presence of moisture or water tree. Partial discharge method uses the level of partial discharge to decide the condition of the cable. Higher level determines higher precaution to the cable. Some of the disadvantages of using partial discharge in monitoring cable condition are the lack of the detection due to low sensitivity of the cable condition and poorly trained test operator

2.3 Harmonics

Harmonic is defines as a sinusoidal component of a periodic wave or quantity having a frequency that is an integral of the fundamental frequency [4].

They are produced by synchronous generator or any non-linear device [5]. Non-linear device is defined when their current is not proportional to voltage [6]. Third harmonic are used in the triplen harmonics for the project because it is the most significant magnitude and the most dominant component compare to the other order of harmonics [7, 8].

Harmonic increases the heat in system especially in neutral system [8]. The excessive heat in cable will eventually lead to degraded cable condition or cable failure [1, 7, 9] that results in decreases of effectiveness of a system.

Cable capacitance plays an important role to investigate the third harmonic in a system. The higher the capacitance, the higher the third harmonic produced when the load is fixed and it will be as high as three times as compare to phase current [10].

CHAPTER 3 METHODOLOGY

3.1 Project Activities

In this project, the research methodologies are divided into six different stages as stated in Figure 2.

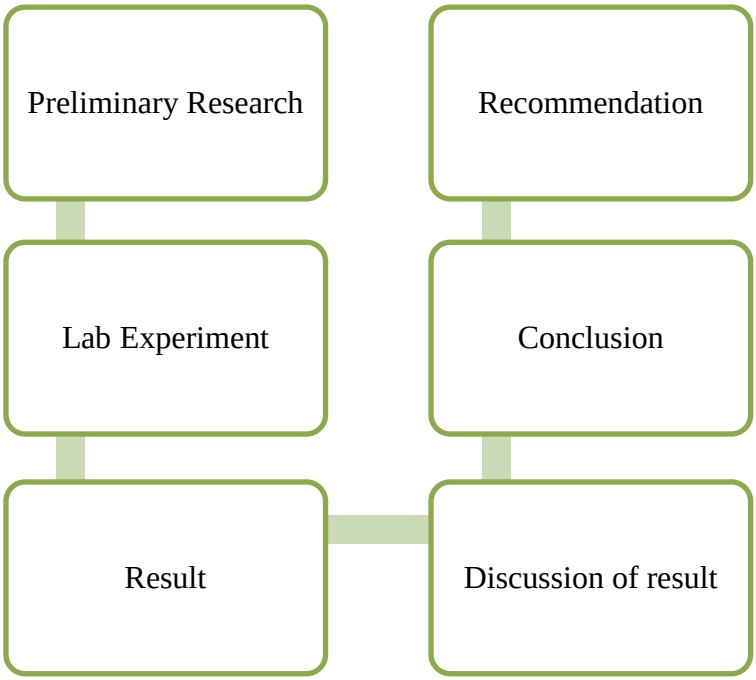

Figure 2: Project Activities

3.1.1 Preliminary Research Work

This stage focuses on data collection related to the project. All information existed from journals, articles, technical papers and books that are related to the project are gathered and compiled to have a better understanding to the project.

Meeting with the previous students are also done to have a better overview regarding the overall projects that will be done including any problems faced and recommendations suggested by the previous students.

3.1.2 Lab Experiment

After all the related information has been gathered, experiments can be carried out to investigate the relationship of third harmonic with the cable capacitance.

In this project, the 0.175kW generator will be used. There will be three types of connections that will be done for this experiments which are listed as following:

1. Generator directly connected with load.

2. Generator connected to transformer (delta-wye) and load.

3. Generator connected to transformer (delta-wye), capacitor and load.

Figure 3, 4 and 5 shows the details of the connections that will be done throughout the experiment and the circle points are the points where the current and voltage of the third harmonic will be measured using the Fluke 435 Power Quality Analyzer as in Figure 6.

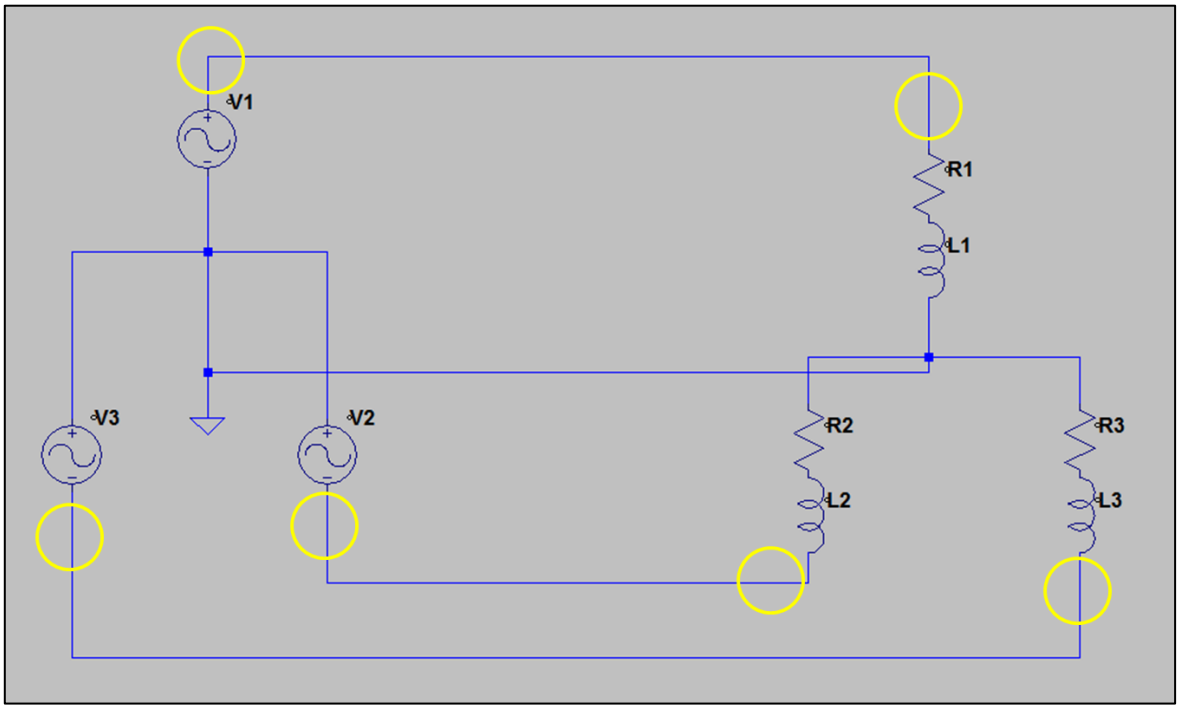

Figure 3: Generator directly connected with load

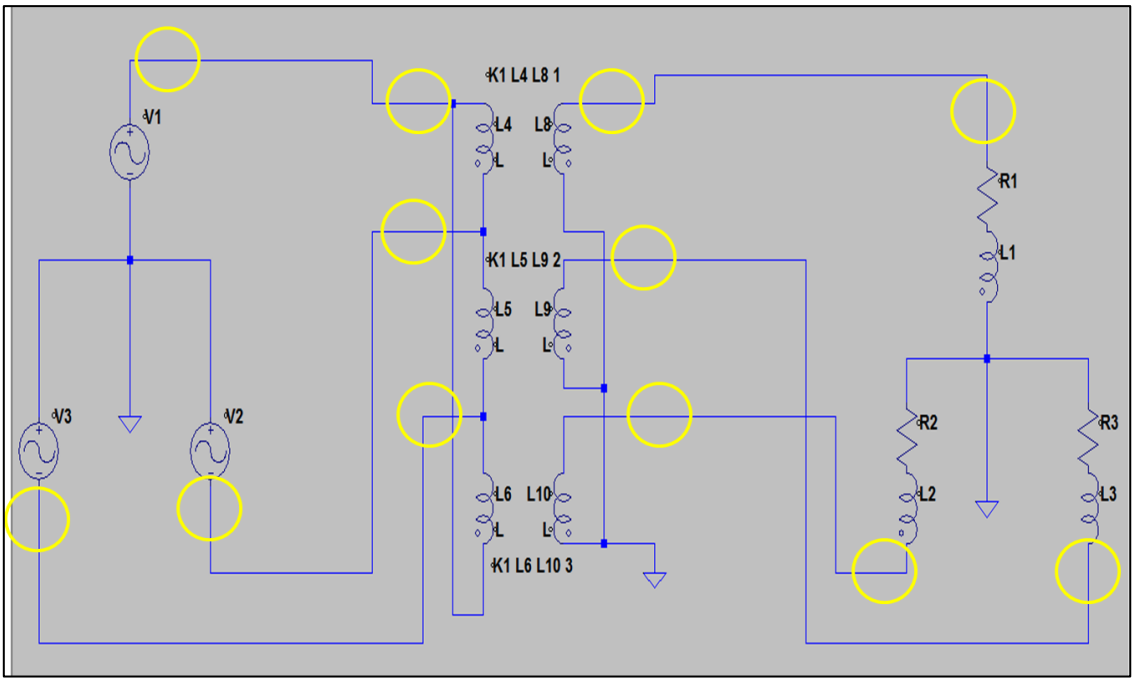

Figure 4: Generator directly connected to transformer (delta-wye) and load

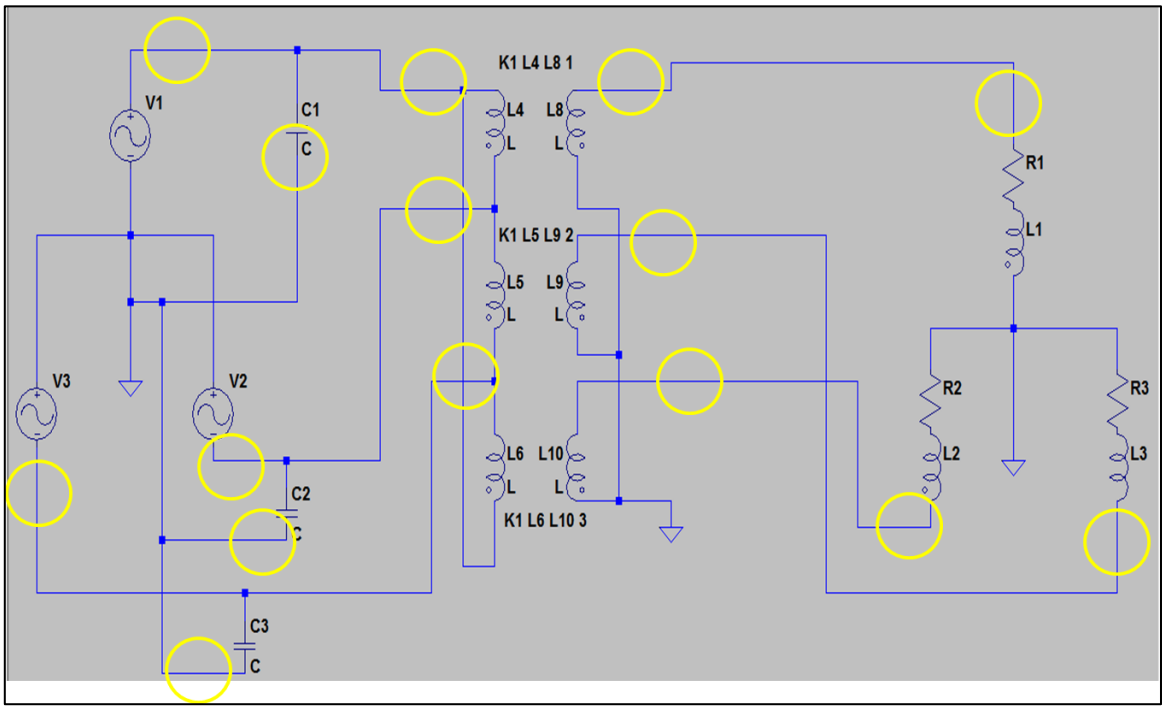

Figure 5: Generator connected to transformer (delta-wye), capacitor and load

Figure 6: Fluke 435 Power Quality Analyzer device to measure the third harmonic current

The generator will be connected to different values of loads. This is to make sure the generator usage is maximized to obtain variety of results.

The loads used for 0.175kW generator are listed in Table 1 and the connections are done as in Figure 7.

Table 1: Loads for 0.175kW generator

Resistance (Ω)	Reactance (Ω)	Inductor (H)
960	660	2.1
1600	1194	3.8
2400	1602	5.1
3600	2388	7.6
4800	3581	11.4

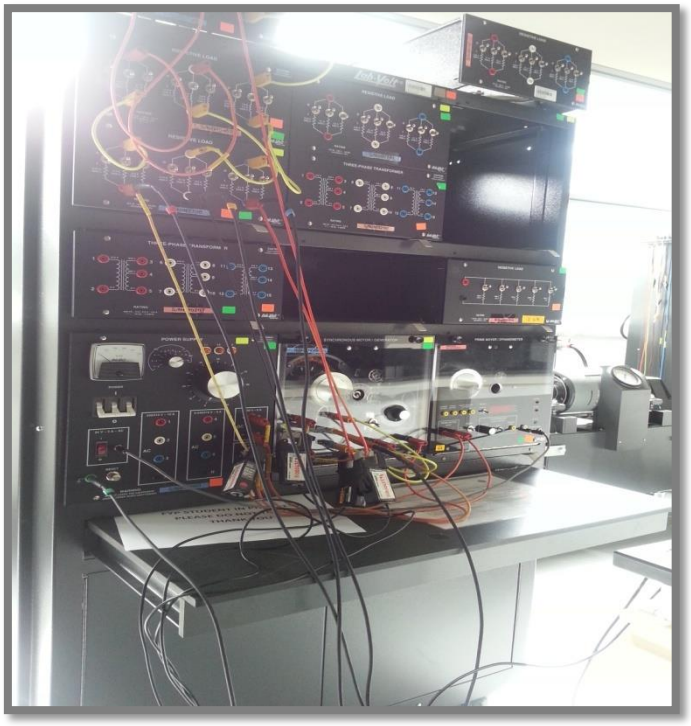

Figure 7: Connection of 0.175kW generator experiment

The loads are setup in parallel of different resistors and inductors available in the lab to obtain the targeted or nearest values for the experiment as shown in Appendix 1 and Appendix 2. For the 0.175kW generator, the loads given have been calculated as following:

First, to calculate the loads suitable for a generator, the rating of the generator must be identified at the plate of the instrument. For the 0.175kW generator, the full load current is 0.17A.

After the full load current is identified, the value of Z is first calculated based on the formula of Z = V / I from the Ohm's Law. Then, when Z value is obtained, the values of resistor, R and impedance, X_L are then calculated based on the relationship of Z, R and X_L as in Figure 8.

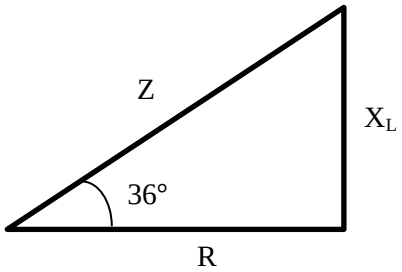

Figure 8: Relationship of Z, R and X_L

The 36° is used in this experiment because power factor of 0.8 is a standard power factor for power system in Malaysia. However, there will be no identical values of 0.8 power factor can be obtained thus the values of load will vary but the power factor will be in the range of 0.8 – 0.85 that corresponds to 32° to 37°.

Based on the relationship from Figure 8, to obtain resistor, R values, the calculation can be done using the formula cos 36° = R / Z and to obtain impedance, X_L values, the calculation can be done using the formula sin 36° = X_L / Z.

After the values of resistor, R and impedance, X_L for full load current are calculated and obtained, the values will be in 100% current and to obtain 5 different values with the same angle, the percentage will be decreased 20% each time. The loads listed in Table 2 shows the value of the loads. However, nearest available value is used as can be seen in Table 1.

Table 2: Calculated loads for 0.175kw generator

%	Amp (A)	angle	Z	R	XL	L
100	0.17	36°	1411.8	1142.1	829.8	2.6
80	0.14	36°	1764.7	1427.7	1037.3	3.3
60	0.10	36°	2352.9	1903.6	1383.0	4.4
40	0.07	36°	3529.4	2855.4	2074.5	6.6
20	0.03	36°	7058.8	5710.7	4149.1	13.2

When calculation of load is calculated, the experiment will be done in two ways of conditions for the capacitor connection. The first one will be in connection of normal, good condition capacitor and damaged condition capacitor to prove the 1st objective which is when the cable insulation is in various conditions and when the 1st objective is done, a discussion is made and a summarization is concluded to come out with the applicability of the project to fulfill the 2nd objective.

The experiment for capacitor that represents the good cable insulation can be easily conducted. However, to modify the capacitor to emulate bad cable insulation is very difficult, due to the capacitor complicated construction based on the Figure 46 and Figure 47.

Figure 9: Internal view of a capacitor

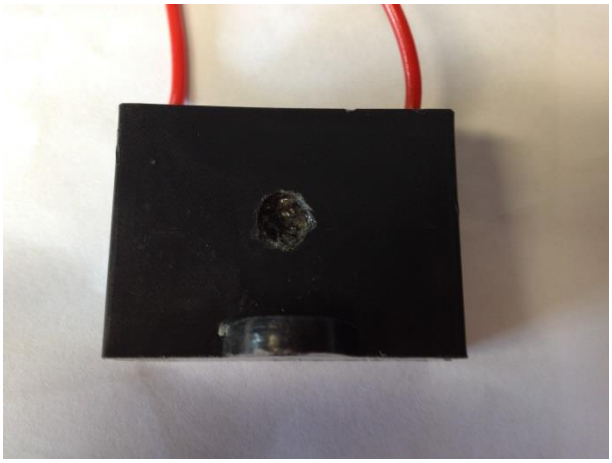

Figure 10: Hole made to damage the capacitor

So, an alternative method is used to complete the project by using the modeling concept of water tree. Figure 11 shows the equivalent circuit of a water tree phenomenon that can be used.

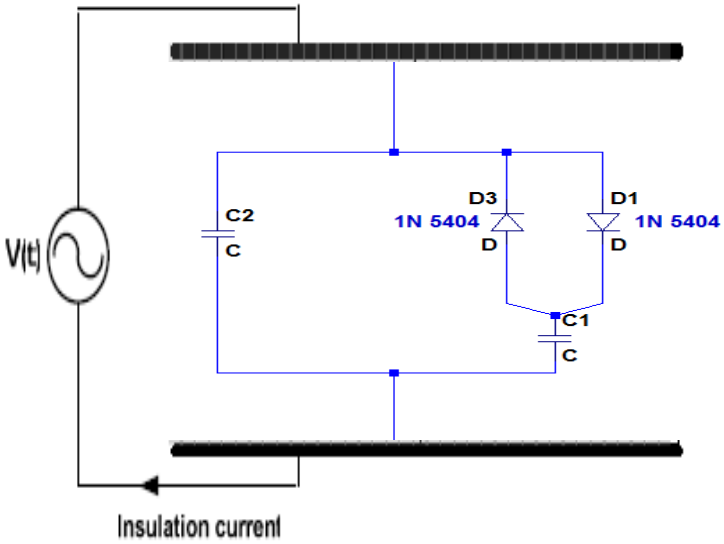

Figure 11: Equivalent circuit of a water tree

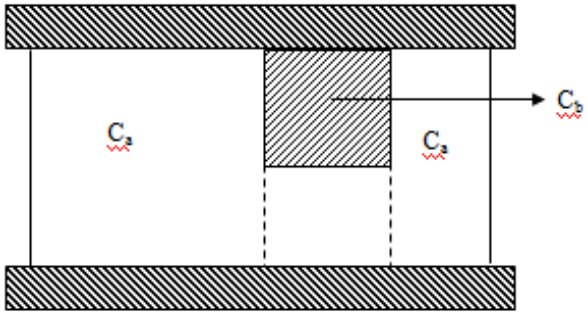

Figure 12: Water tree concept

Figure 12 shows the concept of water tree existed in the cable insulation. C_a shows the total of capacitance for the cable insulation and the C_b shows the existence of water tree in part of the cable insulation. The capacitor aligned with the diode in Figure 11 shows the number of water tree existed in the cable insulation. In this project, the value of capacitor used is 0.55uF and 1uF for capacitor 2uF. The 0.55uF shows 27.5% of water tree existed and 1uF shows 50% of water tree existed. Value of capacitor used for 1uF is 0.22uF and 0.55uF which shows 22% of water tree and 55% of water tree respectively.

The presence of diode in the equivalent circuit is to produce third harmonic which acts as a non-linear load. The diode used is 1N 5404 that is capable to withstand more than 240V for the experiment.

3.3 Key Milestone

Table 3: Key Milestone for Final Year Project 1

No.	Item/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Submission of final year project title selection form														
2	Submission of extended proposal														
3	Proposal defense														
4	Submission of interim draft report														
5	Submission of interim final report														

Table 4: Key Milestone for Final Year Project 2

No.	Item/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Submission of progress report														
2	Electrex														
3	Submission of Draft Report														
4	Final Report														
5	Viva														

3.4 Gantt Chart

Table 5: Gantt Chart of Final Year Project 1

No.	Item/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Select & confirmation of project title														
2	Early research on the proposed topic														
3	Lab experiment														
4	Proposal defense														
5	Preparing interim draft report														
6	Preparing interim final report														

Table 6: Gantt Chart of Final Year Project 2

No.	Item/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Lab Experiment														
2	Preparing Progress Report														
3	Data Analysis														
4	Preparing Final Report														
5	Presentation Preparation														

3.5 Tool & Software Required

Tools & software that will be used throughout the project are:

- Laptop
- Fluke View
- Fluke power quality analyzer
- Microsoft Office (Excel & Word)
- Capacitors
- Inductive Load
- Resistive Load
- Connectors
- Synchronous generator (lab scale)
- Calculator
- Power Supply
- Diode (1N 5404)

Figure 13, 14, 15, 16, 17, 18 and 19 shows some of the equipment used throughout the project.

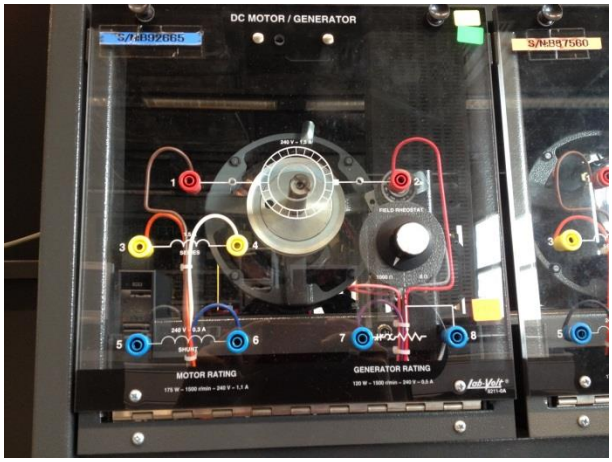

Figure 13: Generator

Figure 14: Power Supply

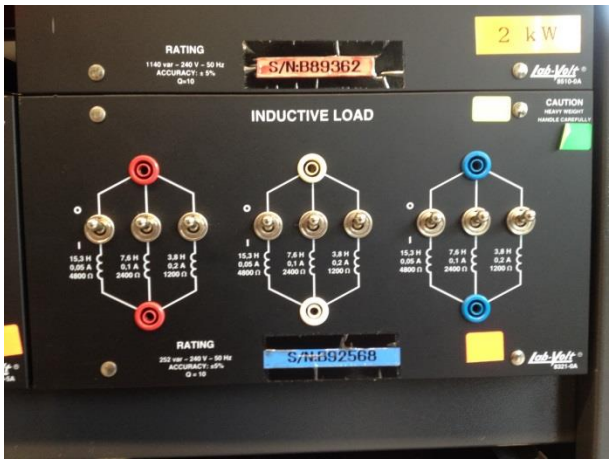

Figure 15: Inductive Load

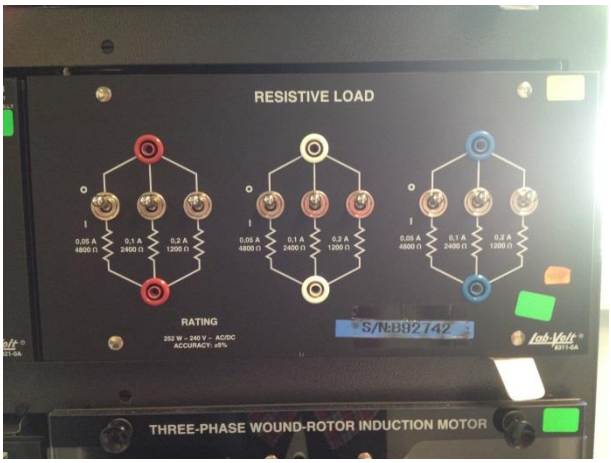

Figure 16: Resistive Load

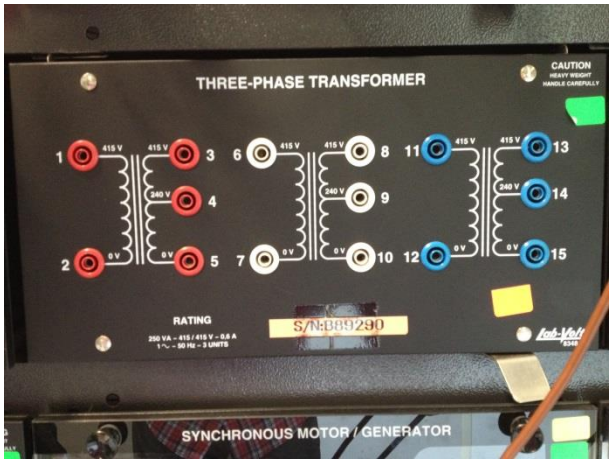

Figure 17: Three-phase Transformer

Figure 18: Capacitors

Figure 19: Connectors

CHAPTER 4 RESULTS

4.1 Generator Directly Connected With Load

Figure 20 shows the detail of the measurement for fundamental voltage and current and also third harmonic phase voltage and phase current including their angle. The V_f is for fundamental voltage, I_f is for fundamental current, V_t for third harmonic voltage and I_t for third harmonic current.

The fundamental phase voltage value shows a correct measurement based on the angle measured that can be seen at each of the phases of V_f with the difference of 120°. The value used for all the three phases are around 240V. The angle of the phase current for the 1st phase is lagging with the symbol of negative to the angle and this is correct due to the presence of inductance load to the connection. The third harmonic phase current angle shows a zero sequence due to their angle is about the same and the amount of neutral line value is the sum of all the three phase lines value.

Figure 21, shows the measurement of third harmonic phase voltage. The figure shows that the third harmonic phase voltage exists in a significant amount in the power system. However, the value of the phase voltage is related to the third harmonic phase current.

Figure 22, shows the measurement of third harmonic phase current. The figure proves that the third harmonic current in neutral is three times from the phase value and the value of third harmonic current for all the three phases are almost the same with significant value.

Appendix B shows the rest of the measurement. The result shows that the higher the load, the lower the current.

	V_f(Volt)	V_f˚(deg)	I_f(mA)	I_f˚(deg)		V_f(Volt)	V_f˚(deg)	I_f(mA)	I_f˚(deg)	
	239.53	0.00	193.7235	-32.4165		239.5290	0.00	193.7235	-32.42	
	239.41	-119.91	190.4161	-153.4120		239.4132	-119.91	190.4161	-153.41	
	239.96	120.40	189.6538	86.8554		239.9568	120.40	189.6538	86.86	
	2.74	35.18	4.017242	42.9645		2.7365	35.18	4.017242	42.96	
Gen										Load
	V_t(Volt)	V_t˚(deg)	I_t(mA)	I_t˚(deg)		V_t(Volt)	V_t˚(deg)	I_t(mA)	I_t˚(deg)	
	10.04	10.04	3.419236	-29.1163		10.03978	10.03813	3.419236	-29.12	
	10.85	15.52	3.891485	-23.9159		10.85044	15.51808	3.891485	-23.92	
	11.94	10.14	4.342153	-26.5648		11.93503	10.14160	4.342153	-26.56	
	5.73	-172.08	11.964300	-28.3963		5.733888	-172.077	11.96430	-28.40	

Figure 20: Measurement for load 960Ω+j660

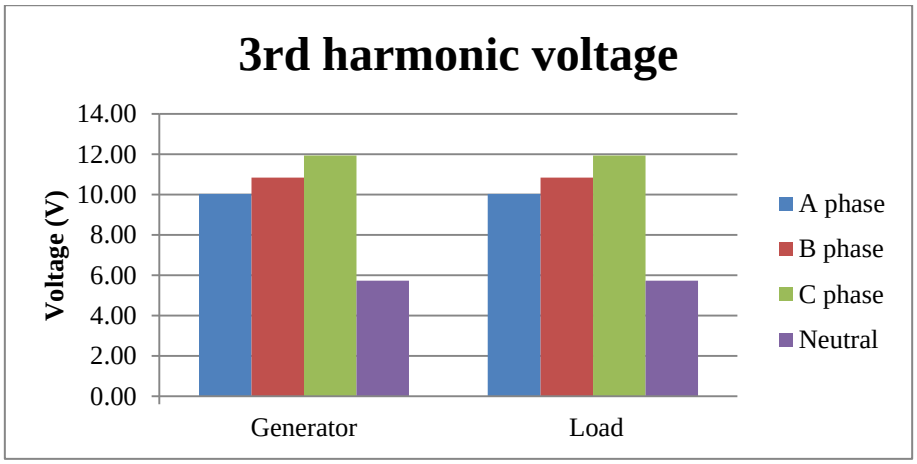

Figure 21: Third harmonic voltage for load 960Ω+j660

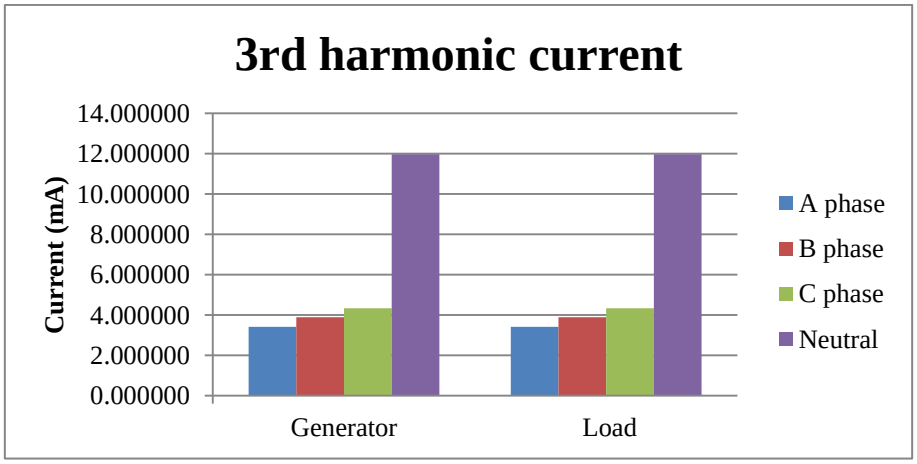

Figure 22: Third harmonic current for load 960Ω+j660

4.2 Generator Connected With Transformer and Load

Figure 23 shows the measurement of third harmonic phase voltage and Figure 24 shows the measurement of third harmonic phase current. Appendix B shows the detailed measurement of the connection for each part of the connection. From the detailed measurement, it shows a correct measurement and connection based on the angle of the fundamental voltage and current. The fundamental voltage has a difference of 120° for each phase and the fundamental current is in lagging due to the presence of inductance for the 1st phase. The third harmonic current shows zero sequence based on the angle of the measurement which is about the same for the three phase angle and the value of the neutral line is sum of all the three phase line.

Figure 24 shows that the delta has higher values of third harmonic phase current and only circulate in the delta transformer thus, the third harmonic inside the connection of wye and load are lesser but still exist. As the load is increased, the value of the third harmonic becomes lesser at the wye and load connection.

The transformer is in Dyn 11 which shows the delta is connected High Voltage (HV) winding, wye connected Low Voltage (LV) winding with neutral brought out and the LV is leading HV with 30°. This can be proven by calculating the difference angle using matlab as following:

```
clear
Ia = <value A>*exp(j*deg2rad(<angle A>));
Ib = <value B>*exp(j*deg2rad(<angle B>));
Ic = <value C>*exp(j*deg2rad(<angle C>));

IA = Ia - Ib
IAmag = abs(IA)
IAang = rad2deg(angle(IA))

IB = Ib - Ic
IBmag = abs(IB)
IBang = rad2deg(angle(IB))
```

IC = Ic - Ia

ICmag = abs(IC)

ICang = rad2deg(angle(IC))

The value inserted in the < > will prove that the value of A phase for delta is 30° difference with the generator angle and also to the rest of the phase.

Appendix C shows the rest of the measurement.

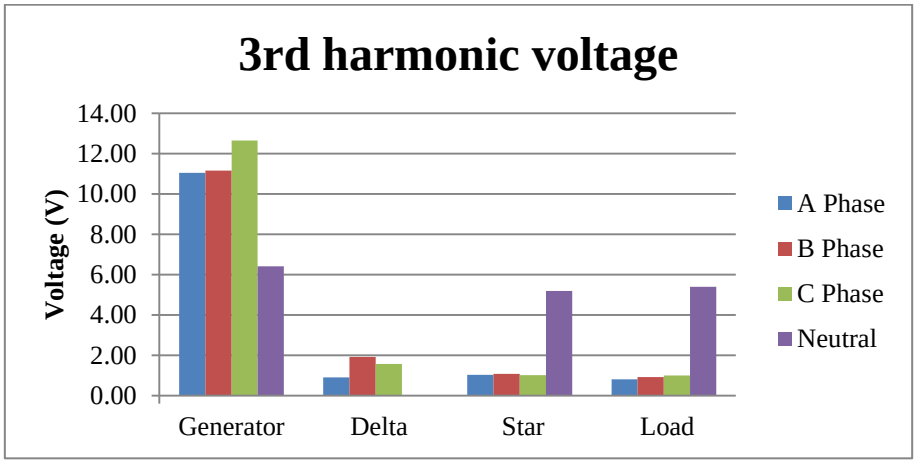

Figure 23: Third harmonic voltage for load 960Ω+j660

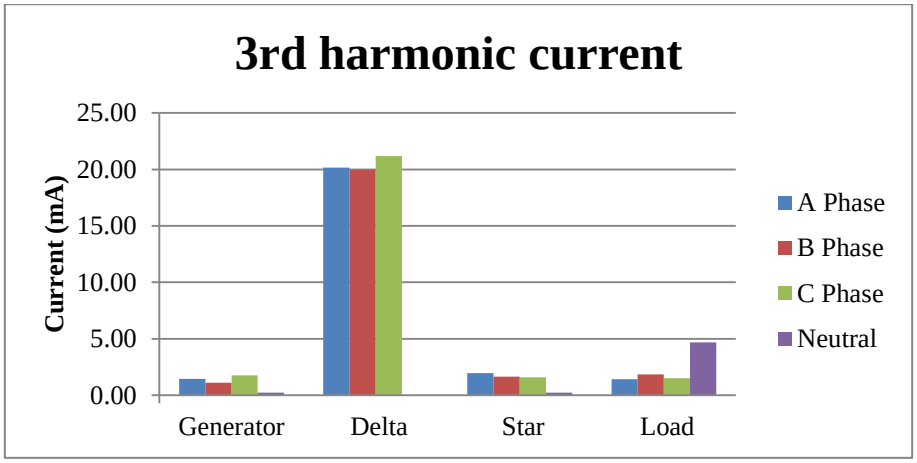

Figure 24: Third harmonic current for load 960Ω+j660

4.3 Generator Connected With Capacitor, Transformer and Load

4.3.1 Normal, Good Condition Capacitor, 2uf

Figure 25 shows the measurement of third harmonic phase voltage. It shows the value of third harmonic current at delta is high because it only circulates in the delta connection. The value of the third harmonic current at capacitor is almost the same as the delta which shows that the value of 2uF enable the third harmonic current to flow. The value of the third harmonic current at neutral line is sum of all three phase line value.

Figure 26 shows the measurement of third harmonic phase current. At the neutral line, the third harmonic current is sum of all the three phases at the generator connection and the capacitor connection.

Appendix D shows the detailed measurement of the fundamental and third harmonic phase voltage and phase current. It shows the angle of the current for generator becoming positive or leading as the load in increased. This is due to the presence of capacitor that has the characteristic of leading current.

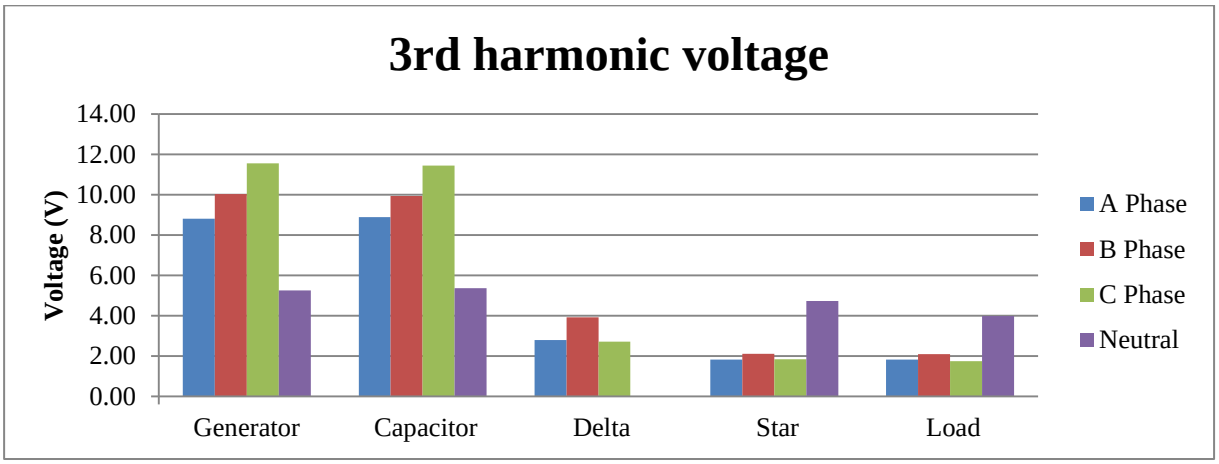

Figure 25: Third harmonic voltage for load 960Ω+j660 (2uF)

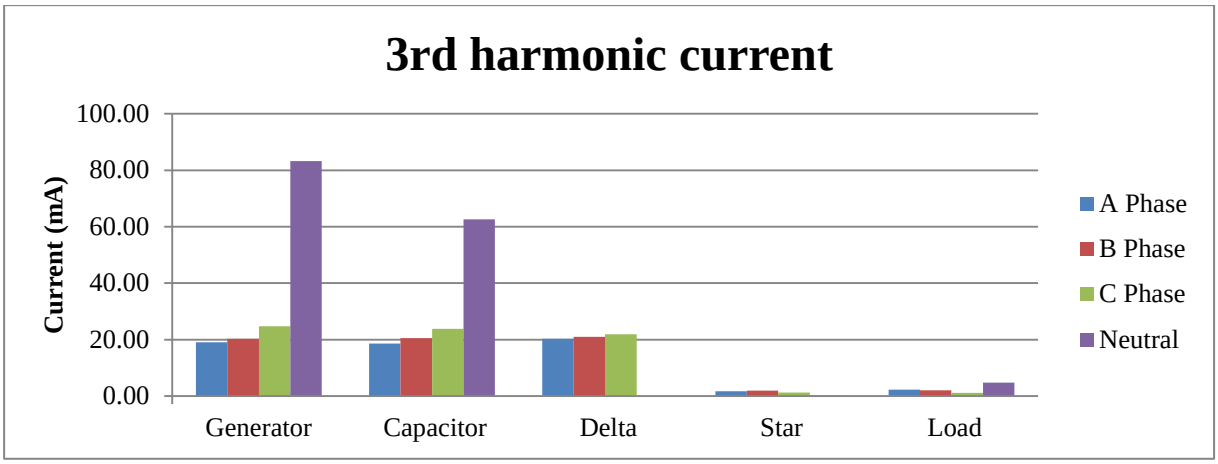

Figure 26: Third harmonic current for load 960Ω+j660 (2uF)

4.3.2 Damaged Condition Capacitor, 2uf with 0.55uF (27.5% of water tree)

Figure 27 shows the third harmonic phase voltage. From the graph, it shows that with the presence of 0.55uF at A phase, the voltage value drops while at B phase and C phase with no additional presence of capacitor, shows a similar result with the normal condition capacitor.

Figure 28 shows the third harmonic phase current. From the graph, it shows that with the presence of 0.55uF at A phase, the current value increases a bit. This shows that with the presence of water tree, the third harmonic produces will be increased and the value is quite significant as compare to the normal condition capacitor.

Appendix E shows the detailed measurement of the fundamental and third harmonic phase voltage and phase current. It shows the angle of the current for generator becoming positive or leading as the load in increased. This is due to the presence of capacitor that has the characteristic of leading current.

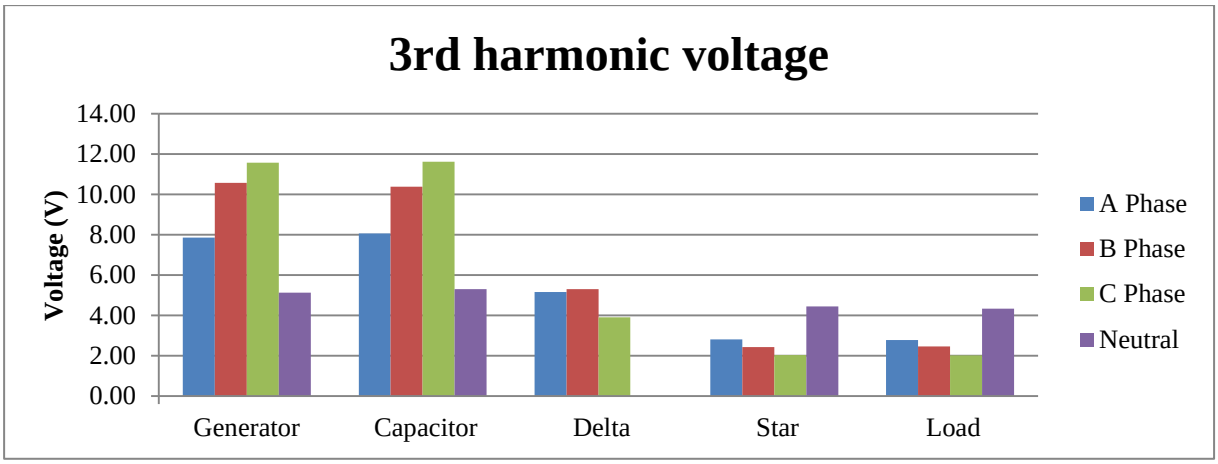

Figure 27: Third harmonic voltage for load 960Ω+j660 (2uF+0.55uF)

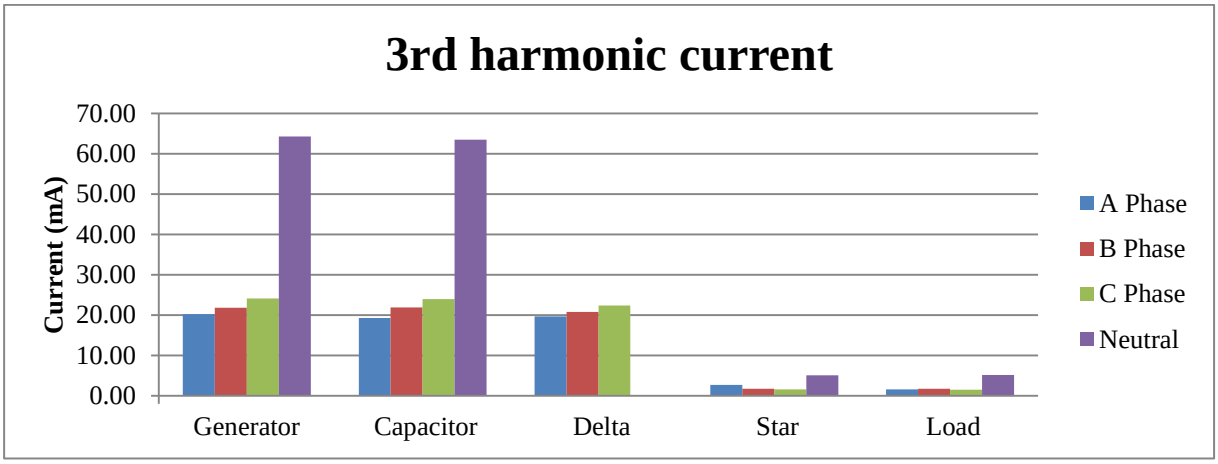

Figure 28: Third harmonic current for load 960Ω+j660 (2uF+0.55uF)

4.3.3 Damaged Condition Capacitor, 2uf with 1uF (50% of water tree)

Figure 29 shows the third harmonic phase voltage. From the graph, it shows that with the presence of 1uF at A phase, the voltage value drops significantly while at B phase and C phase with no additional presence of capacitor, shows a similar result with the normal condition capacitor.

Figure 30 shows the third harmonic phase current. From the graph, it shows that with the presence of 1uF at A phase, the current value decreases significantly.

Appendix F shows the detailed measurement of the fundamental and third harmonic phase voltage and phase current. It shows the angle of the current for generator becoming

positive or leading as the load in increased. This is due to the presence of capacitor that has the characteristic of leading current.

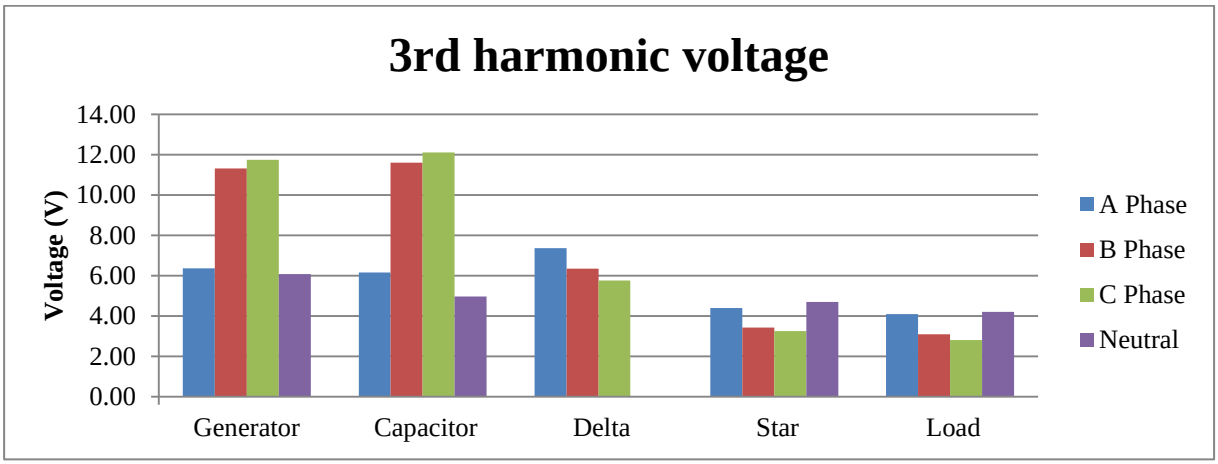

Figure 29: Third harmonic voltage for load 960Ω+j660 (2uF+1uF)

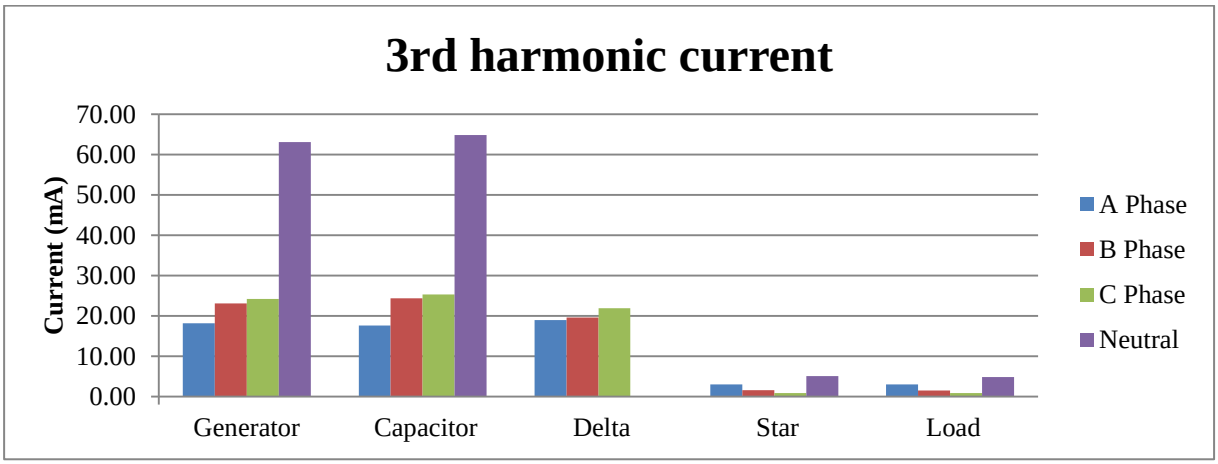

Figure 30: Third harmonic current for load 960Ω+j660 (2uF+1uF)

4.3.4 Normal, Good Condition Capacitor, 1uF

Figure 31 shows the measurement of third harmonic phase voltage. It shows the value of third harmonic current at delta is high because it only circulates in the delta connection. The value of the third harmonic current at capacitor is lesser than the delta which shows that the value of 1uF enables the third harmonic current to flow but not as effective as 2uF. The value of the third harmonic current at neutral line is sum of all three phase line value.

Figure 32 shows the measurement of third harmonic phase current. At the neutral line, the third harmonic current is sum of all the three phases at the generator connection and the capacitor connection.

Appendix G shows the detailed measurement of the fundamental and third harmonic phase voltage and phase current. It shows the angle of the current for generator becoming positive or leading as the load in increased. This is due to the presence of capacitor that has the characteristic of leading current.

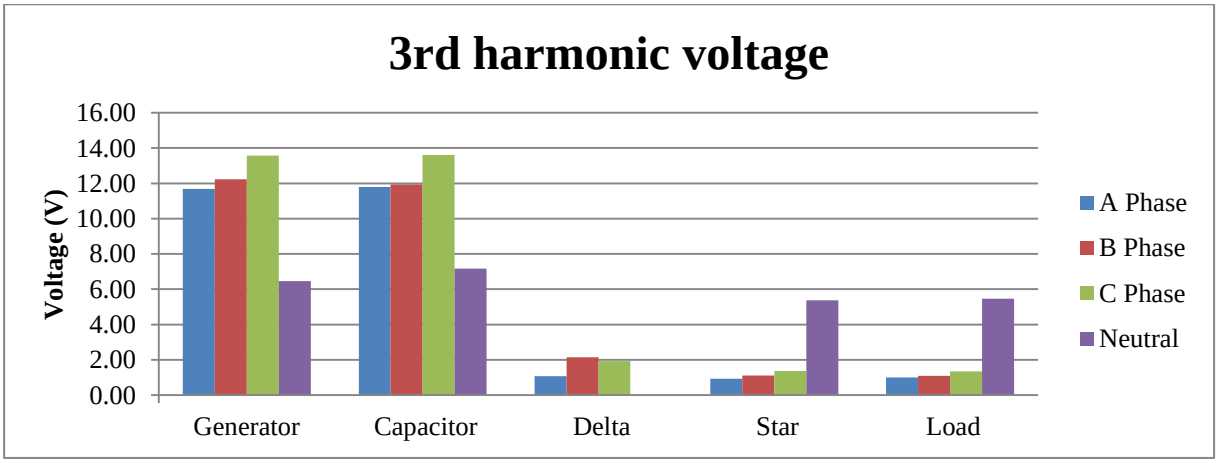

Figure 31: Third harmonic voltage for load 960Ω+j660 (1uF)

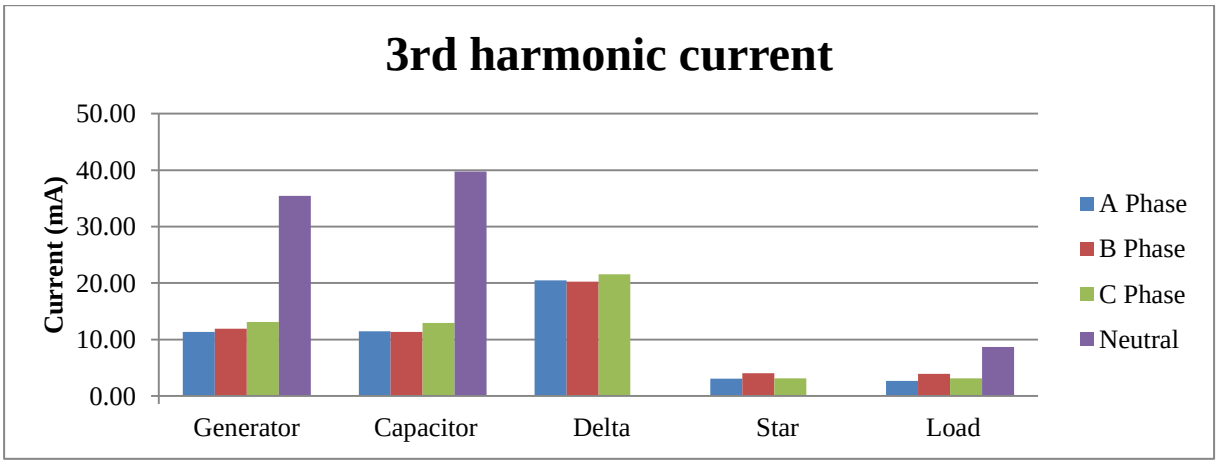

Figure 32: Third harmonic current for load 960Ω+j660 (1uF)

4.3.5 Damaged Condition Capacitor, 1uf with 0.22uF (22% of water tree)

Figure 33 shows the third harmonic phase voltage. From the graph, it shows that with the presence of 0.22uF at A phase, the voltage value drops significantly while at B phase and C phase with no additional presence of capacitor, shows a similar result with the normal condition capacitor.

Figure 34 shows the third harmonic phase current. From the graph, it shows that with the presence of 0.22uF at A phase, the current value increases a bit. This shows that with the presence of water tree, the value of third harmonic current flows will increases.

Appendix H shows the detailed measurement of the fundamental and third harmonic phase voltage and phase current. It shows the angle of the current for generator becoming positive or leading as the load in increased. This is due to the presence of capacitor that has the characteristic of leading current.

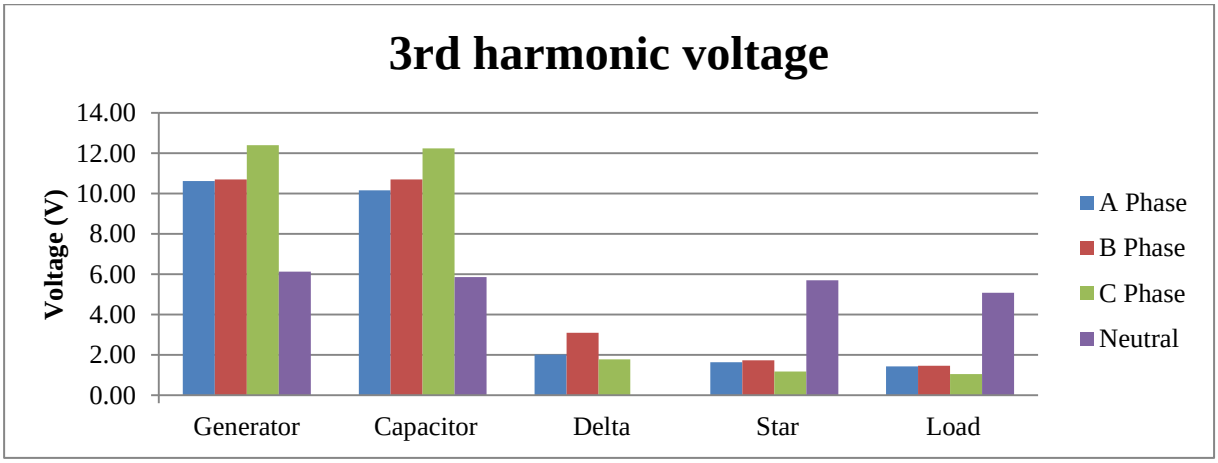

Figure 33: Third harmonic voltage for load 960Ω+j660 (1uF+0.22uF)

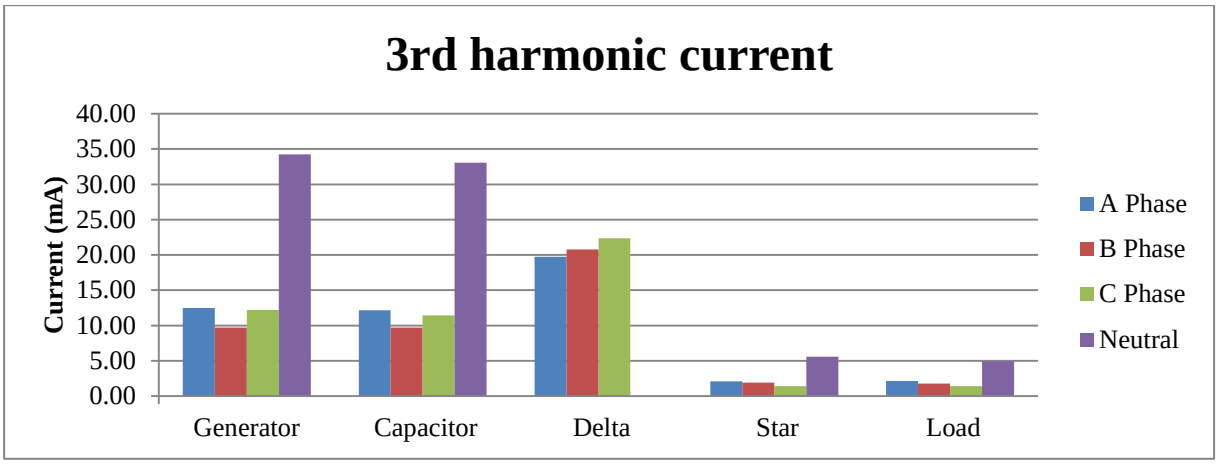

Figure 34: Third harmonic current for load 960Ω+j660 (1uF+0.22uF)

4.3.6 Damaged Condition Capacitor, 1uf with 0.55uF (55% of water tree)

Figure 35 shows the third harmonic phase voltage. From the graph, it shows that with the presence of 0.55uF at A phase, the voltage value increases while at B phase and C phase with no additional presence of capacitor, shows a similar result with the normal condition capacitor.

Figure 36 shows the third harmonic phase current. From the graph, it shows that with the presence of 1uF at A phase, the current value increases significantly. This shows that with the presence of water tree, the value of third harmonic current flows will increases. By comparing with the normal condition capacitor, the value obtained is obviously different.

Appendix I shows the detailed measurement of the fundamental and third harmonic phase voltage and phase current. It shows the angle of the current for generator becoming positive or leading as the load in increased. This is due to the presence of capacitor that has the characteristic of leading current.

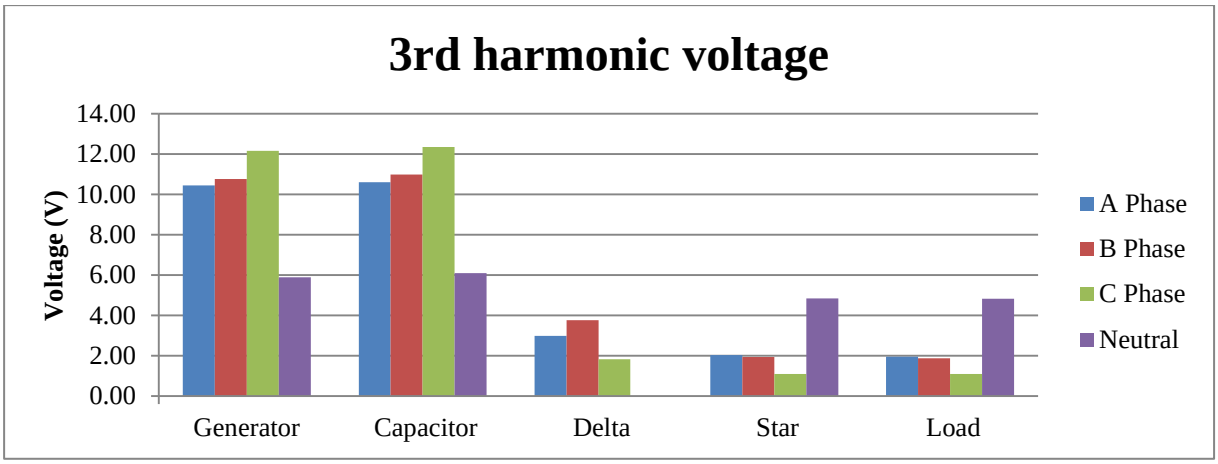

Figure 35: Third harmonic voltage for load 960Ω+j660 (1uF+0.55uF)

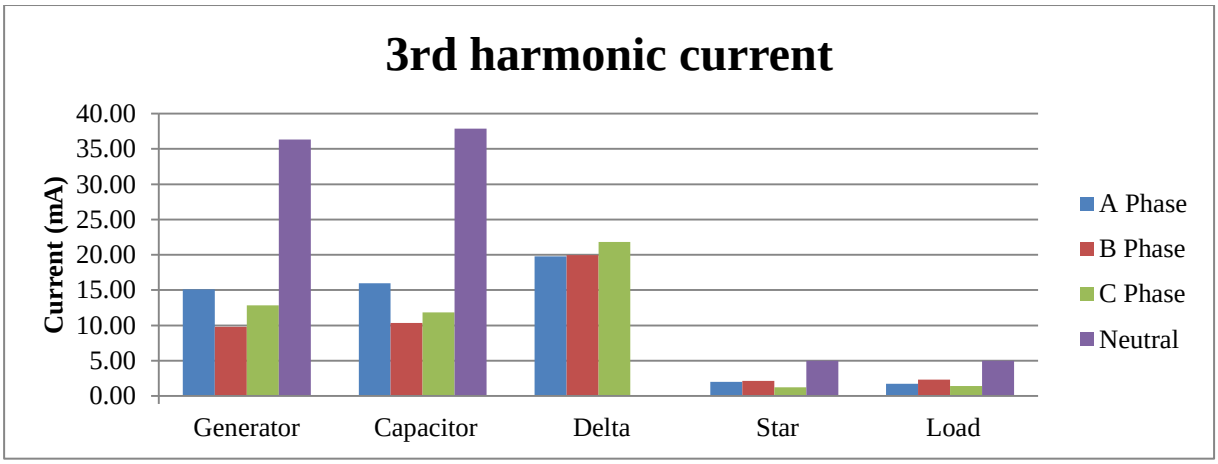

Figure 36: Third harmonic current for load 960Ω+j660 (1uF+0.55uF)

CHAPTER 5 CONCLUSION & RECOMMENDATION

5.1 Conclusion

The results for the first and second part of the experiment show that they are somehow similar as the previous students' research. This indicates that the measurement is correct with suitable load are connected to the specific generator.

The 1st objective third harmonic voltage and current characteristic for good cable insulation can be obtained with the value of 2uF and 1uF capacitor value. The harmonics flow into the capacitors and delta which shows the signature of the cable in good condition. By adding diode and capacitor as an equivalent circuit of water tree, the signature of the measurement shows that the value of third harmonic flows in the presence of water tree is higher when comparing with the normal conditional of capacitor thus obtaining the 2nd objective of the project.

5.2 Recommendation

Different values of load and capacitor can be used to vary the result of the project. By using more values, an accurate and more details of signature from the changes of third harmonic can be concluded.

The equivalent circuit of water tree also can be changed by adding a resistor to model the presence of air resistance and water resistance which can be more realistic as to compare with the real study case.

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APPENDICES

Appendix A: Load Connection

Table 7 & Table 8 show the load connection for the available value of resistor and inductor in the lab. I in the table show that the connection is done in series connection and II shows that the connection is done in parallel connection.

Table 7: Inductance Load Connection

H	15.3	7.6	3.80	15.3	7.6	3.8
2.17	II	II	II			
3.8			I			
5.08	II	II				
7.6		I				
11.4		I				I

Table 8: Resistance Load Connection

Ω	4800	2400	1200	4800	2400	1200
4800		I			I	
3600		I				I
2400		I				
1600	II	II				
960	II		II			

Appendix B: Generator Directly Connected With Load

V_f(Volt)	V_f˚(deg)	I_f(mA)	I_f˚(deg)	V_f(Volt)	V_f˚(deg)	I_f(mA)	I_f˚(deg)
220.16	0.00	104.4642	-33.8367	239.135	0.00	113.0050	-33.6629
219.88	-119.924	103.2935	-155.0751	238.929	-119.958	110.9788	-155.168
220.31	120.398	101.6316	85.3940	239.445	120.396	110.8513	84.9343
1.97	17.9819	1.540751	43.5447	0.6004	28.8581	2.3311	38.8426

Gen — Load

V_t(Volt)	V_t˚(deg)	I_t(mA)	I_t˚(deg)	V_t(Volt)	V_t˚(deg)	I_t(mA)	I_t˚(deg)
9.90	-2.46436	2.581021	-63.2197	10.90534	-1.77283	2.105114	-36.2252
10.57	4.31282	2.638173	-46.4647	11.59094	3.97333	2.586094	-31.6019
11.61	-1.84781	2.552837	-42.2969	12.64886	-1.38348	2.551895	-38.4004
6.09	178.742	6.815247	-38.5910	7.16826	178.919	7.445146	-38.9837

Figure 37: Measurement for load 1600Ω+j1194

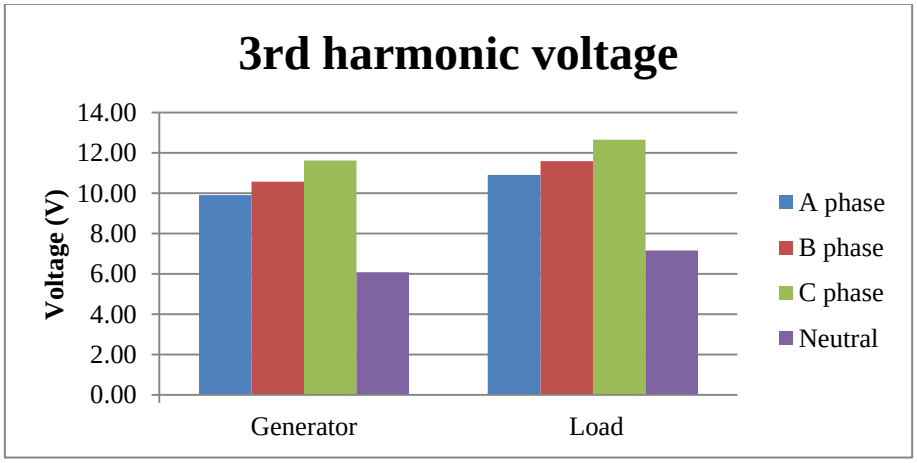


Figure 38: Third harmonic voltage for load 1600Ω+j1194

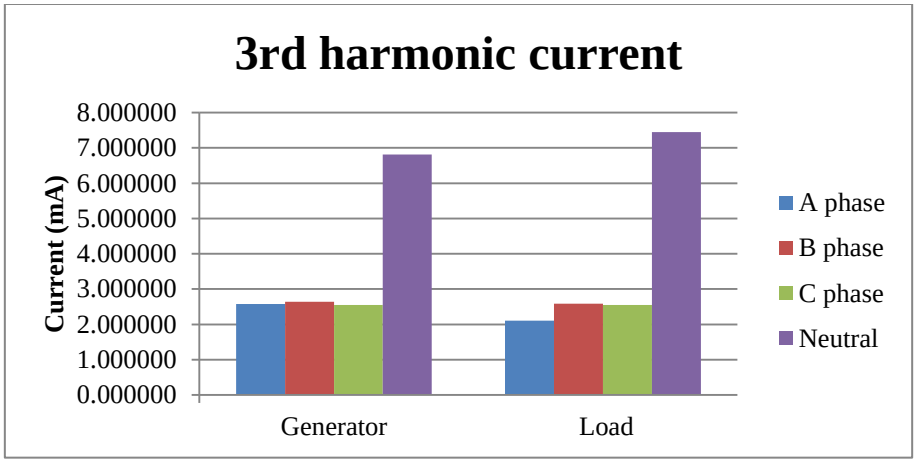


Figure 39: Third harmonic current for load 1600Ω+j1194

	V_f(Volt)	V_f˚(deg)	I_f(mA)	I_f˚(deg)		V_f(Volt)	V_f˚(deg)	I_f(mA)	I_f˚(deg)	
	240.43	0.000	79.53339	-29.841		240.408	0.000	79.57972	-29.688	
	239.99	-119.893	78.50328	-151.066		240.009	-119.981	77.94242	-150.932	
	240.68	120.435	77.63435	89.956		240.498	120.419	78.16107	89.668	
	2.42	-57.023	1.06528	68.789		3.139	-117.263	1.47965	91.820	
Gen										Load
	V_t(Volt)	V_t˚(deg)	I_t(mA)	I_t˚(deg)		V_t(Volt)	V_t˚(deg)	I_t(mA)	I_t˚(deg)	`
	11.02	-7.33	1.34637	-63.5791		11.15	-6.284	1.66620	-57.872	
	11.70	1.02	1.37623	-47.2724		11.67	0.000	1.43964	-41.137	
	12.70	-4.44	1.82529	-63.6162		12.67	-4.129	1.65275	-53.611	
	6.66	175.77	5.71483	-52.6528		6.70	175.036	5.27837	-52.724	

Figure 40: Measurement for load 2400Ω+j1602

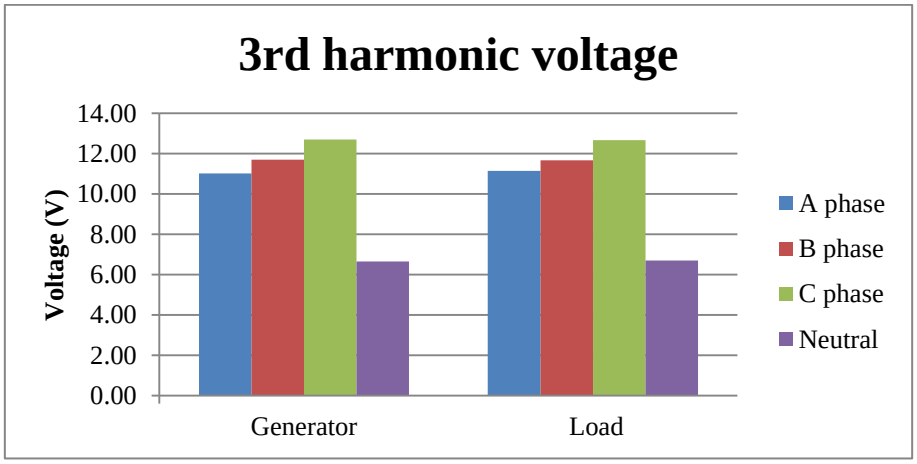


Figure 41: Third harmonic voltage for load 2400Ω+j1602

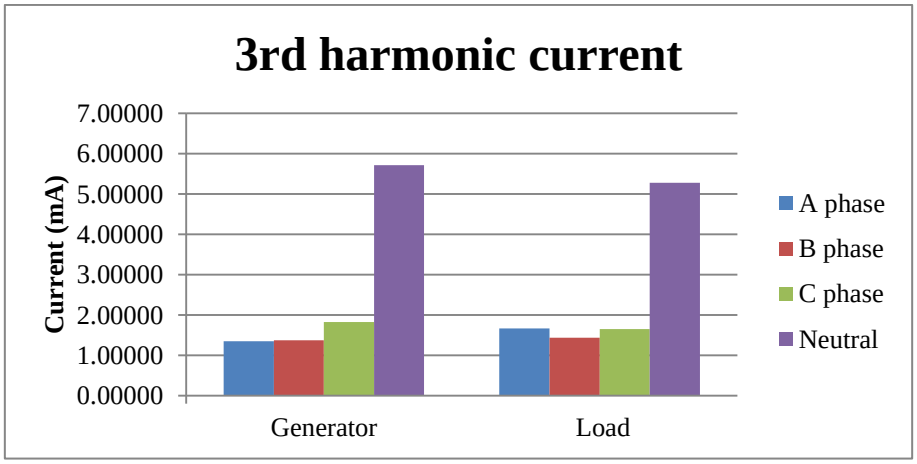


Figure 42: Third harmonic current for load 2400Ω+j1602

	V_f(Volt)	V_f˚(deg)	I_f(mA)	I_f˚(deg)		V_f(Volt)	V_f˚(deg)	I_f(mA)	I_f˚(deg)	
	239.76	0.00	53.05314	-29.32		239.66	0.00	53.21070	-29.25	
	239.40	-120.01	51.68415	-149.32		239.17	-119.98	51.80730	-149.94	
	239.85	120.41	51.62676	89.37		239.75	120.45	51.86851	89.59	
	2.38	-87.83	0.901932	38.37		1.86	-112.59	0.933978	25.60	
Gen										Load
	V_t(Volt)	V_t˚(deg)	I_t(mA)	I_t˚(deg)		V_t(Volt)	V_t˚(deg)	I_t(mA)	I_t˚(deg)	`
	11.43	-11.23	0.772650	-53.39		11.46	-10.95	1.045300	-65.56	
	11.98	-4.75	0.758982	-7.54		11.88	-4.50	1.030727	-52.11	
	12.84	-8.54	0.672708	-24.61		12.99	-8.52	1.094934	-57.75	
	6.89	171.86	10.13148	-80.62		6.70	169.06	8.244536	-74.04	

Figure 43: Measurement for load 3600Ω+j2388

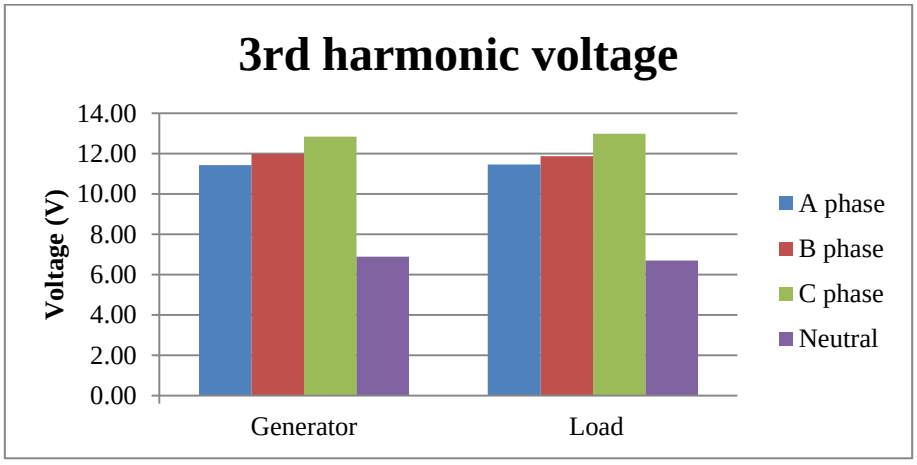


Figure 44: Third harmonic voltage for load 3600Ω+j2388

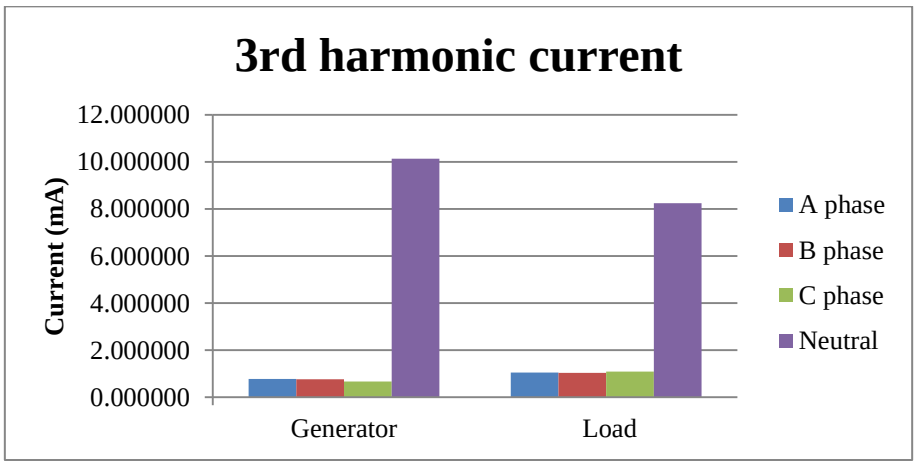


Figure 45: Third harmonic current for load 3600Ω+j2388

	V_f(Volt)	V_f˚(deg)	I_f(mA)	I_f˚(deg)		V_f(Volt)	V_f˚(deg)	I_f(mA)	I_f˚(deg)	
	239.92	0.00	38.18106	-31.07		240.12	0.00	37.99895	-31.71	
	239.63	-120.02	36.57915	-152.34		239.78	-120.02	37.17347	-153.15	
	240.03	120.39	37.14051	87.00		239.98	120.39	37.84365	86.26	
	2.52	-80.26	0.598664	21.00		3.30	-88.11	0.807847	8.14	
Gen										Load
	V_t(Volt)	V_t˚(deg)	I_t(mA)	I_t˚(deg)		V_t(Volt)	V_t˚(deg)	I_t(mA)	I_t˚(deg)	`
	11.54	-14.29	1.228973	-153.38		11.60	-14.17	0.587682	-42.02	
	12.10	-7.98	0.947317	-142.54		12.19	-7.90	0.565385	-42.70	
	12.91	-12.00	0.856306	-82.44		12.93	-11.88	0.557008	-54.34	
	6.89	168.33	2.746718	-71.35		7.09	167.97	2.114999	-69.68	

Figure 46: Measurement for load 4800Ω+j3581

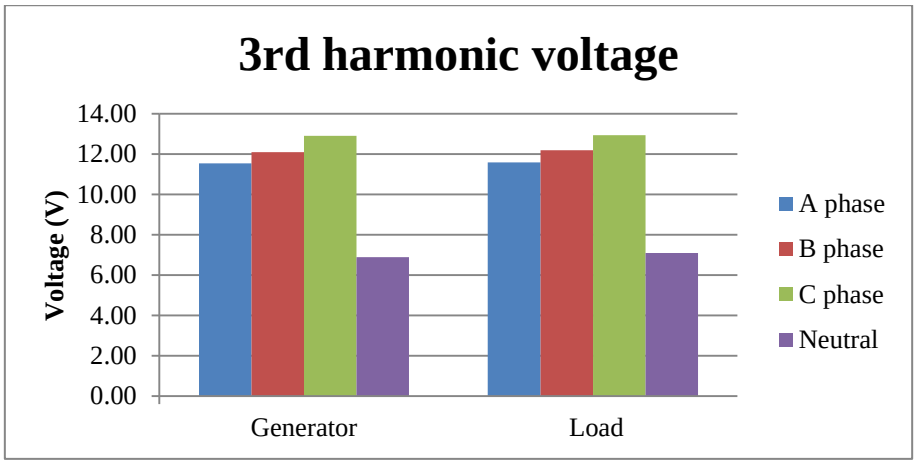


Figure 47: Third harmonic voltage for load 4800Ω+j3581

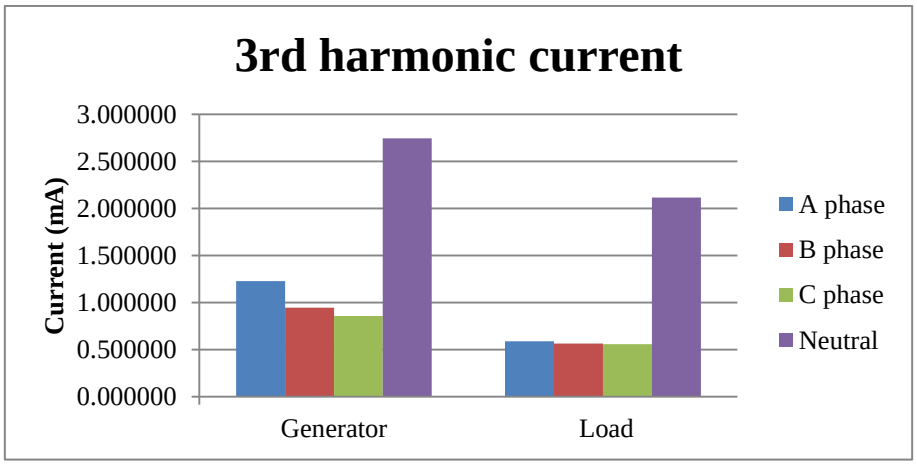
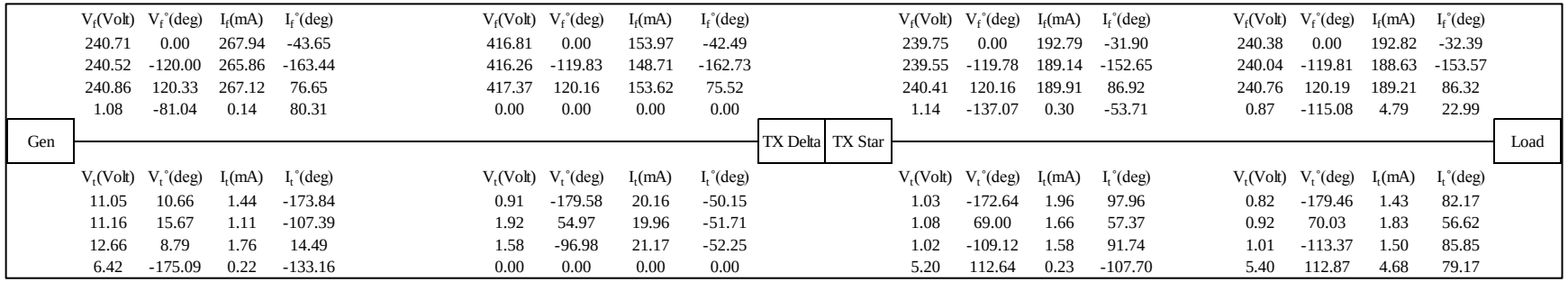


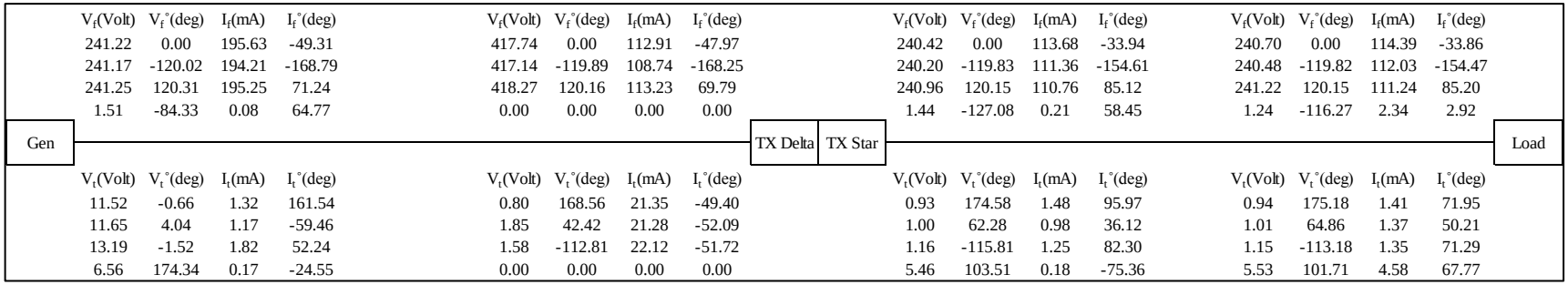
Figure 48: Third harmonic current for load 4800Ω+j3581

Appendix C: Generator Connected With Transformer and Load



V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)	V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)	V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)	V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
240.71	0.00	267.94	-43.65	416.81	0.00	153.97	-42.49	239.75	0.00	192.79	-31.90	240.38	0.00	192.82	-32.39
240.52	-120.00	265.86	-163.44	416.26	-119.83	148.71	-162.73	239.55	-119.78	189.14	-152.65	240.04	-119.81	188.63	-153.57
240.86	120.33	267.12	76.65	417.37	120.16	153.62	75.52	240.41	120.16	189.91	86.92	240.76	120.19	189.21	86.32
1.08	-81.04	0.14	80.31	0.00	0.00	0.00	0.00	1.14	-137.07	0.30	-53.71	0.87	-115.08	4.79	22.99
V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)	V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)	V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)	V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
11.05	10.66	1.44	-173.84	0.91	-179.58	20.16	-50.15	1.03	-172.64	1.96	97.96	0.82	-179.46	1.43	82.17
11.16	15.67	1.11	-107.39	1.92	54.97	19.96	-51.71	1.08	69.00	1.66	57.37	0.92	70.03	1.83	56.62
12.66	8.79	1.76	14.49	1.58	-96.98	21.17	-52.25	1.02	-109.12	1.58	91.74	1.01	-113.37	1.50	85.85
6.42	-175.09	0.22	-133.16	0.00	0.00	0.00	0.00	5.20	112.64	0.23	-107.70	5.40	112.87	4.68	79.17

Figure 49: Measurement for load 960Ω+j660



V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)	V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)	V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)	V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
241.22	0.00	195.63	-49.31	417.74	0.00	112.91	-47.97	240.42	0.00	113.68	-33.94	240.70	0.00	114.39	-33.86
241.17	-120.02	194.21	-168.79	417.14	-119.89	108.74	-168.25	240.20	-119.83	111.36	-154.61	240.48	-119.82	112.03	-154.47
241.25	120.31	195.25	71.24	418.27	120.16	113.23	69.79	240.96	120.15	110.76	85.12	241.22	120.15	111.24	85.20
1.51	-84.33	0.08	64.77	0.00	0.00	0.00	0.00	1.44	-127.08	0.21	58.45	1.24	-116.27	2.34	2.92
V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)	V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)	V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)	V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
11.52	-0.66	1.32	161.54	0.80	168.56	21.35	-49.40	0.93	174.58	1.48	95.97	0.94	175.18	1.41	71.95
11.65	4.04	1.17	-59.46	1.85	42.42	21.28	-52.09	1.00	62.28	0.98	36.12	1.01	64.86	1.37	50.21
13.19	-1.52	1.82	52.24	1.58	-112.81	22.12	-51.72	1.16	-115.81	1.25	82.30	1.15	-113.18	1.35	71.29
6.56	174.34	0.17	-24.55	0.00	0.00	0.00	0.00	5.46	103.51	0.18	-75.36	5.53	101.71	4.58	67.77

Figure 50: Measurement for load 1600Ω+j1194

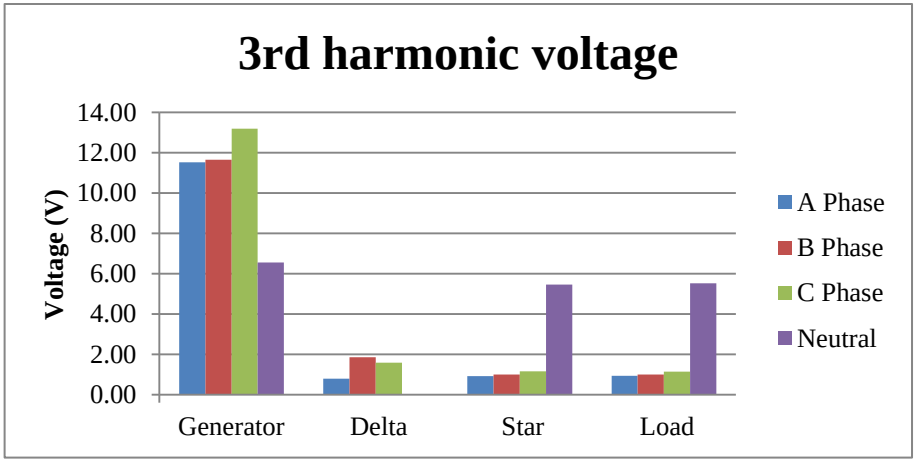


Figure 51: Third harmonic voltage for load 1600Ω+j1194

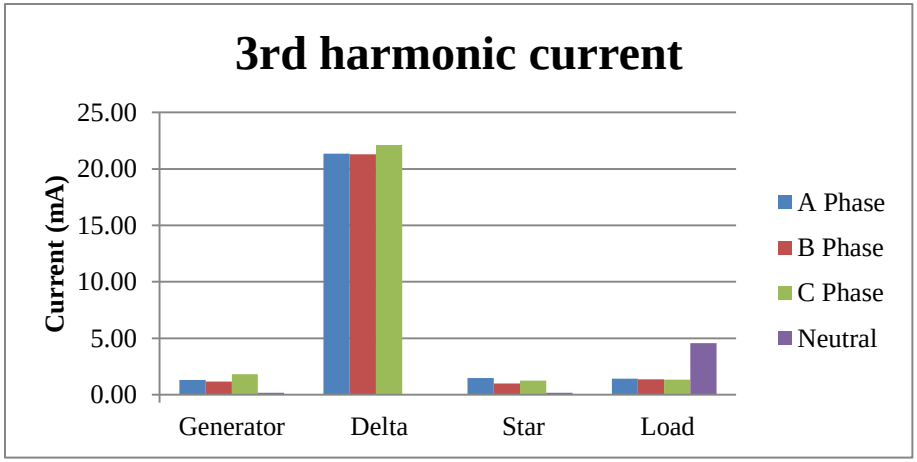


Figure 52: Third harmonic current for load 1600Ω+j1194

	V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)	V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)		V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)	V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)	
	240.38	0.00	161.07	-50.31	417.99	0.00	93.28	-50.03		240.16	0.00	79.43	-29.92	240.57	0.00	80.33	-29.37	
	240.48	-120.05	158.81	-169.88	417.53	-119.87	88.61	-167.95		239.92	-119.86	77.50	-150.39	240.11	-119.80	77.99	-149.95	
	240.50	120.32	160.21	70.50	418.75	120.09	93.21	69.08		240.48	120.14	77.64	89.83	240.84	120.24	78.16	90.11	
	1.81	-78.21	0.08	65.60	0.00	0.00	0.00	0.00		1.80	-119.38	0.19	57.02	1.60	-107.64	1.42	-2.96	
Gen									TX Delta									Load
	V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)	V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)		V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)	V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)	
	11.77	-3.57	1.47	162.78	1.06	158.21	20.45	-49.12		0.78	173.92	0.98	124.70	0.72	-173.23	0.52	62.30	
	11.76	0.03	1.12	-61.87	2.06	44.41	19.50	-52.68		0.95	54.06	0.38	63.02	0.97	80.87	0.70	66.69	
	13.21	-4.64	2.23	47.21	1.93	-107.19	21.75	-52.83		1.12	-129.43	0.54	128.56	0.95	-118.41	0.33	75.55	
	6.54	171.25	0.14	-34.45	0.00	0.00	0.00	0.00		5.50	101.03	0.18	-45.93	5.42	98.63	1.59	93.45	

Figure 53: Measurement for load 2400Ω+j1602

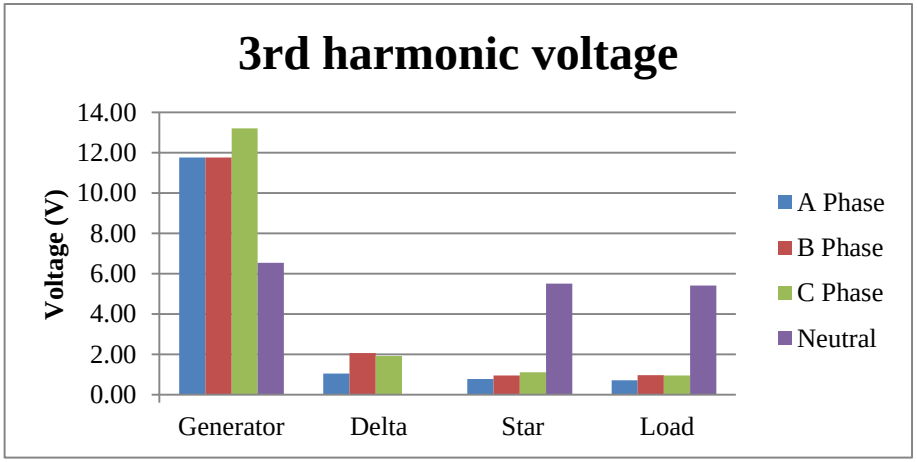


Figure 54: Third harmonic voltage for load 2400Ω+j1602

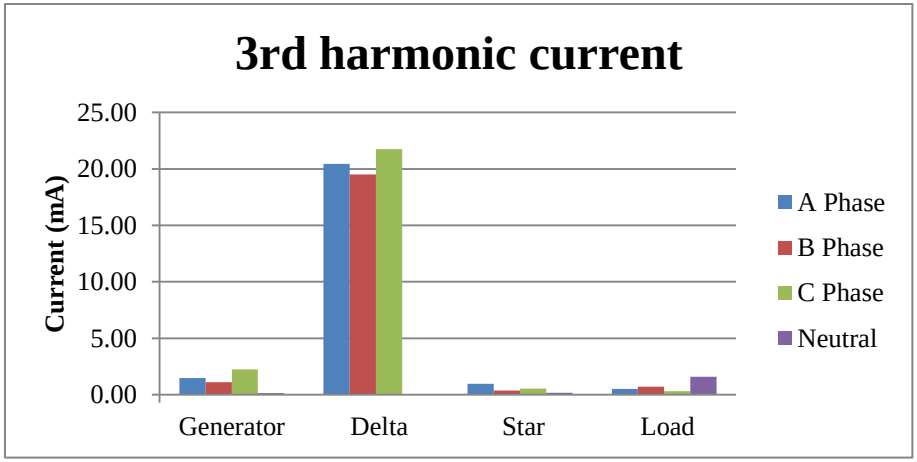


Figure 55: Third harmonic current for load 2400Ω+j1602

	V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)	V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)	V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)	V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)	
	240.26	0.00	135.86	-54.05	416.43	0.00	77.67	-53.08	240.57	0.00	53.23	-28.27	240.44	0.00	53.93	-28.91	
	240.34	-120.10	132.73	-173.32	415.88	-119.85	73.08	-170.95	240.38	-119.85	51.82	-149.29	240.31	-119.85	51.95	-149.23	
	240.43	120.24	134.60	67.15	417.05	120.14	78.24	64.90	241.14	120.12	51.74	89.91	240.99	120.12	51.91	89.86	
	1.96	-79.30	0.13	14.38	0.00	0.00	0.00	0.00	2.06	-116.78	0.21	-59.21	1.74	-108.23	2.10	-17.20	
Gen																	Load
	V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)	V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)	V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)	V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)	
	12.09	-6.88	1.73	159.70	0.97	172.54	20.79	-50.35	0.93	172.36	0.75	93.32	0.90	172.68	0.45	55.78	
	12.16	-3.46	0.78	-75.45	2.03	45.38	20.50	-53.40	0.99	56.02	0.11	-97.59	0.98	58.17	0.36	37.75	
	13.43	-9.19	1.77	64.73	1.64	-106.56	22.27	-53.04	1.14	-122.39	0.30	110.05	1.14	-122.02	0.25	71.23	
	6.35	166.37	0.14	44.66	0.00	0.00	0.00	0.00	5.49	95.64	0.20	-141.41	5.39	94.44	0.80	83.73	

TX Delta | TX Star

Figure 56: Measurement for load 3600Ω+j2388

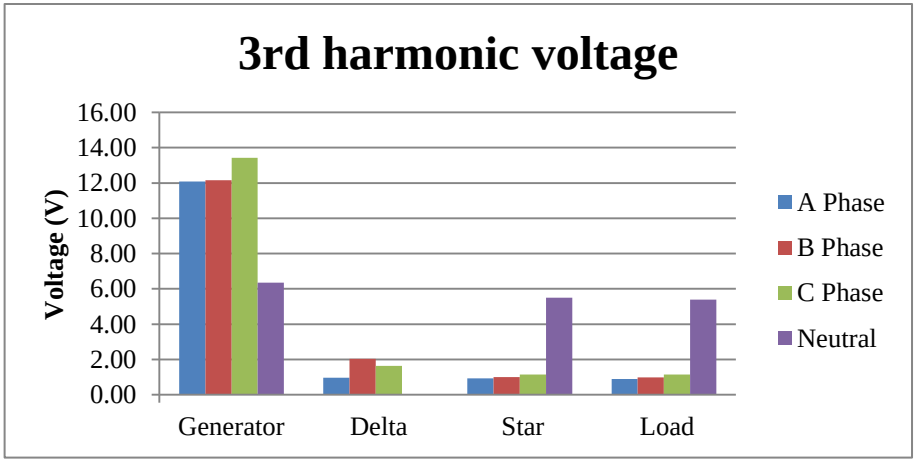


Figure 57: Third harmonic voltage for load 3600Ω+j2388

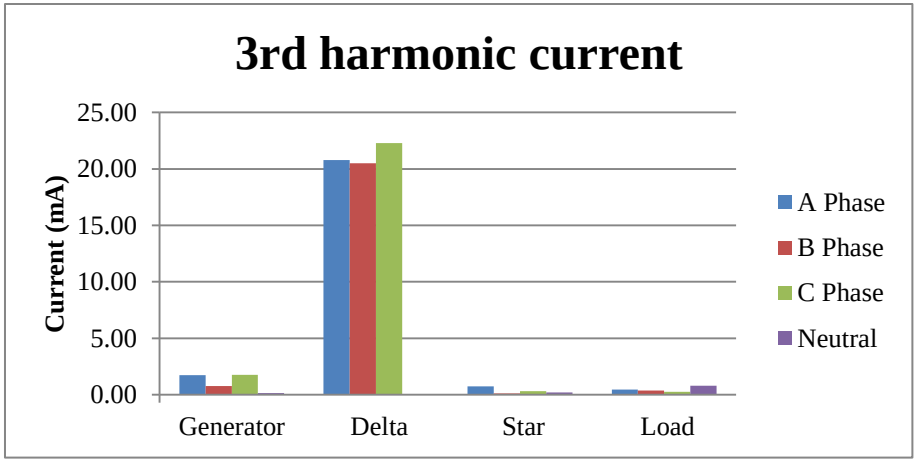


Figure 58: Third harmonic current for load 3600Ω+j2388

	V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)	V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)		V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)	V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)	
	241.35	0.00	120.96	-57.38	417.14	0.00	70.76	-56.47		240.72	0.00	37.90	-30.60	240.43	0.00	38.12	-31.73	
	241.36	-120.06	117.40	-176.85	416.72	-119.86	66.76	-176.26		240.37	-119.89	37.09	-152.31	240.16	-119.86	37.39	-152.20	
	241.48	120.29	119.14	64.07	417.84	120.13	71.67	62.47		240.87	120.16	36.85	88.30	240.91	120.15	36.84	88.07	
	1.93	-89.51	0.10	35.51	0.00	0.00	0.00	0.00		2.15	-127.93	0.19	-133.97	1.46	-121.80	1.01	-37.86	
Gen									TX Delta									Load
	V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)	V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)		V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)	V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)	
	12.50	-9.41	1.52	159.90	0.86	169.33	21.27	-48.52		0.72	173.38	0.65	134.17	0.80	176.72	0.32	-159.53	
	12.51	-5.75	1.10	-79.11	1.96	44.51	20.39	-51.28		0.80	55.28	0.22	-23.30	0.93	57.02	0.30	-88.75	
	13.98	-10.41	1.78	56.96	1.63	-109.76	21.87	-51.25		1.02	-133.28	0.21	127.89	1.06	-127.92	0.28	-170.88	
	6.50	163.83	0.28	45.08	0.00	0.00	0.00	0.00		5.32	93.28	0.31	-30.90	5.34	92.75	0.90	119.03	

Figure 59: Measurement for load 4800Ω+j3581

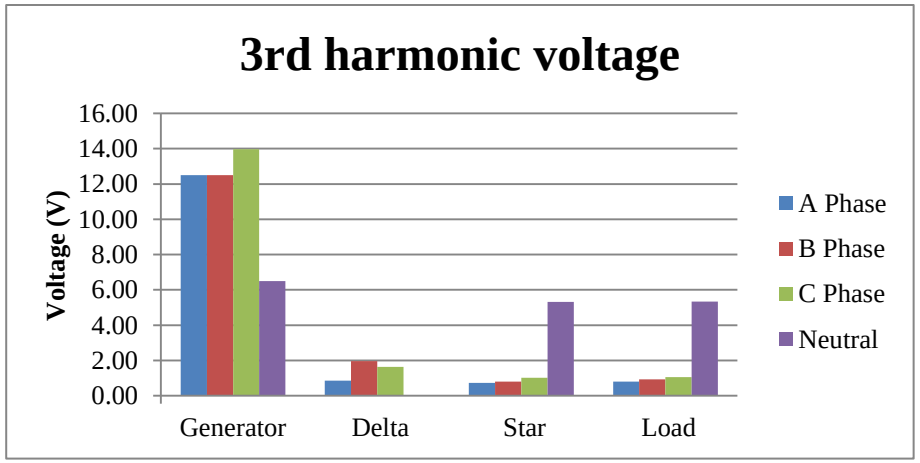


Figure 60: Third harmonic voltage for load 4800Ω+j3581

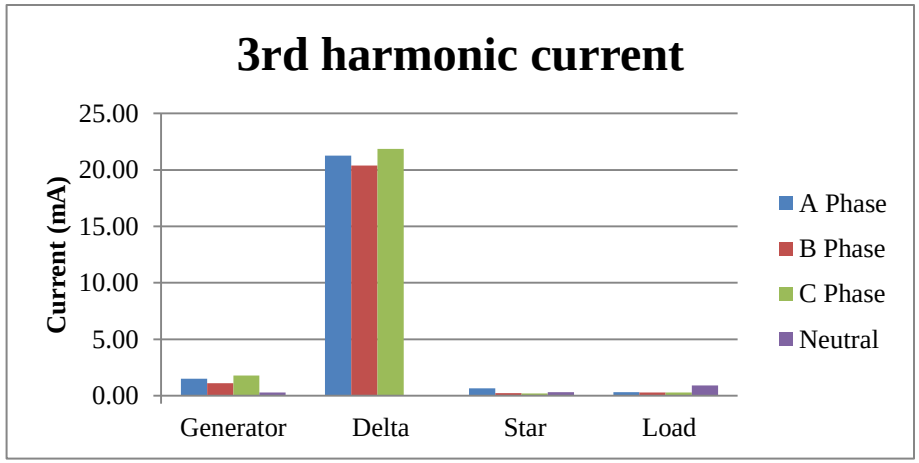


Figure 61: Third harmonic current for load 4800Ω+j3581

Appendix D: Generator Connected With Capacitor, Transformer and Load (2uF)

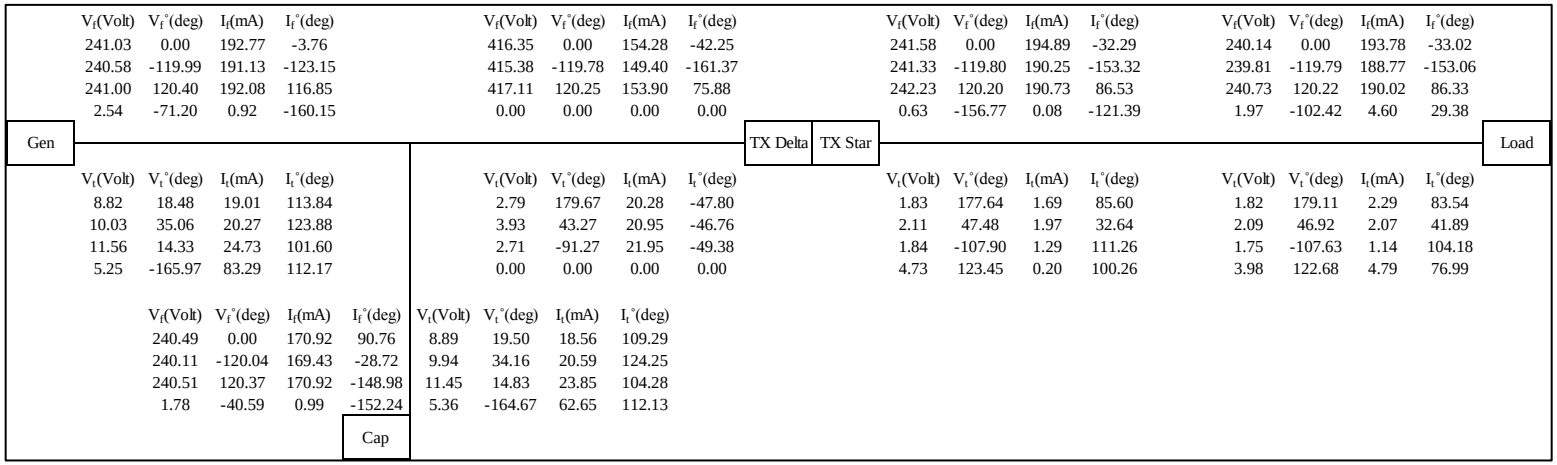


Figure 62: Measurement for load 960Ω+j660 (2uF)

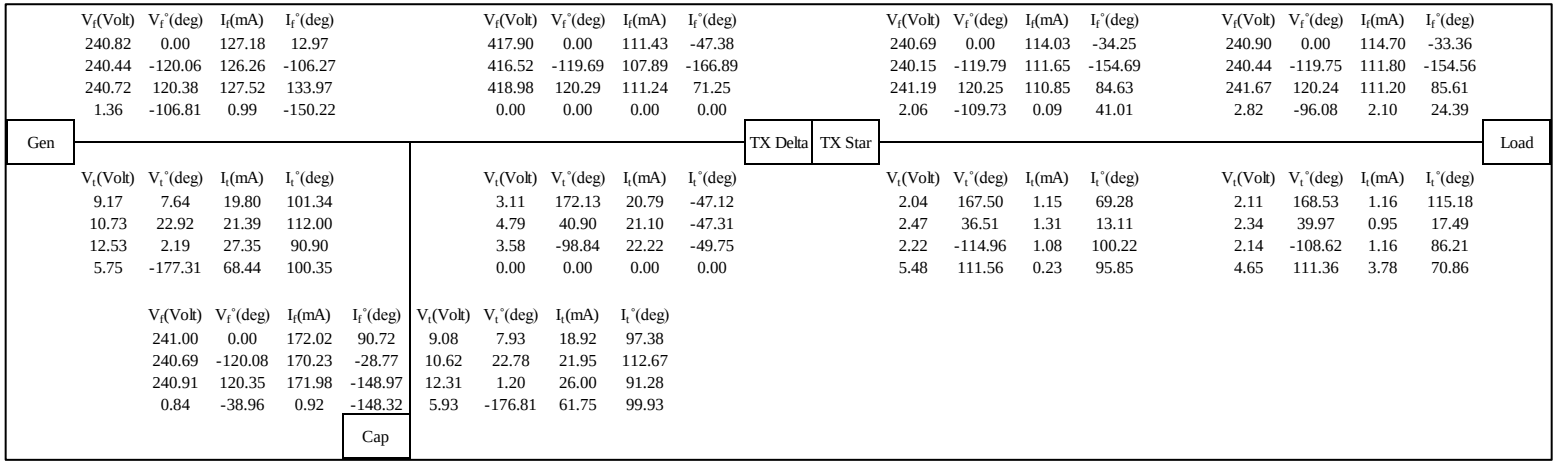


Figure 63: Measurement for load 1600Ω+j1194 (2uF)

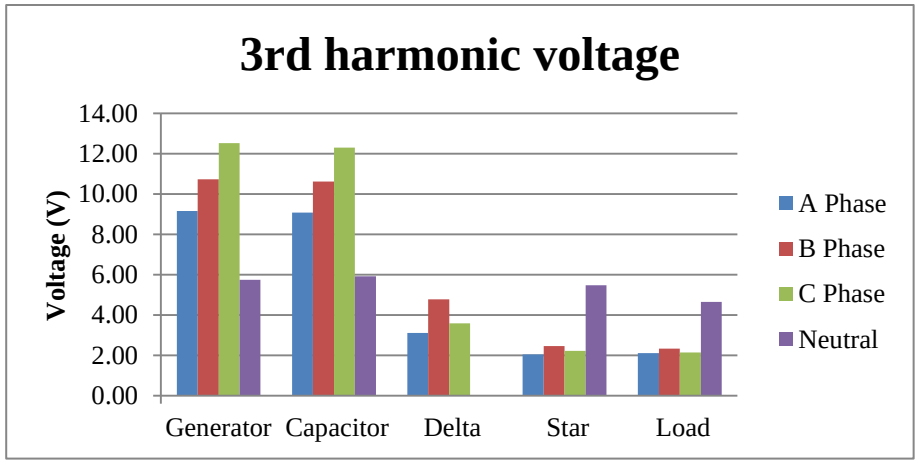


Figure 64: Third harmonic voltage for load 1600Ω+j1194 (2uF)

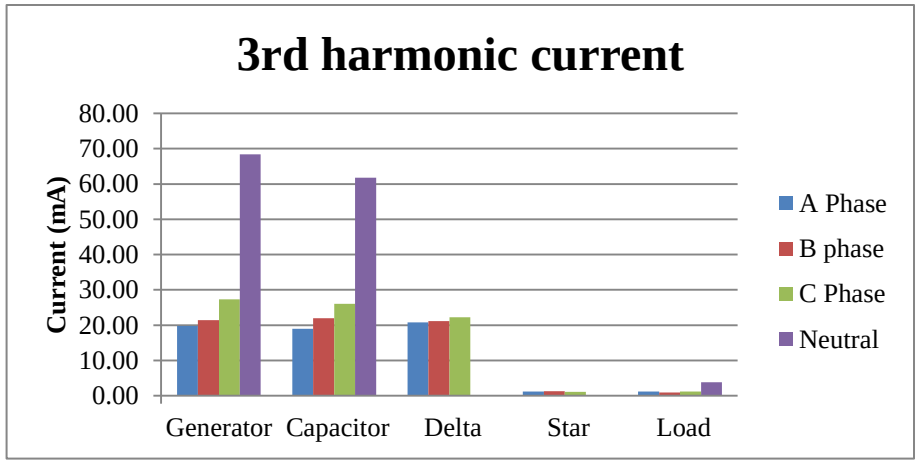


Figure 65: Third harmonic current for load 1600Ω+j1194 (2uF)

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
242.14	0.00	112.12	24.50
241.75	-120.01	111.09	-94.00
242.14	120.41	113.49	145.94
1.64	-93.67	0.91	-147.50

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
427.29	0.00	92.90	-54.74
426.46	-119.76	88.97	-173.65
428.22	120.22	93.10	63.65
0.00	0.00	0.00	0.00

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
244.15	0.00	81.14	-29.62
243.64	-119.76	79.19	-150.47
244.63	120.24	)0*0.0789	89.70
1.76	-121.29	0.08	-85.98

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
240.83	0.00	80.25	-29.19
240.43	-119.74	78.22	-150.32
241.62	120.19	78.18	90.19
3.26	-95.66	1.17	46.70

Gen | TX Delta | TX Star | Load

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
9.22	2.51	20.42	97.75
10.45	18.00	21.53	105.69
12.40	-3.41	25.76	83.18
5.54	178.80	75.18	94.71

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
2.62	152.25	23.13	-44.90
4.35	26.18	22.03	-48.01
3.51	-116.68	23.47	-48.74
0.00	0.00	0.00	0.00

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
2.06	167.42	1.35	114.47
2.50	32.57	0.52	68.17
2.17	-120.15	0.37	140.28
7.47	108.15	0.19	-76.45

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
2.27	164.71	1.30	77.27
2.54	32.53	0.80	38.30
2.21	-114.85	0.43	178.78
4.69	106.55	1.56	95.74

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
241.34	0.00	172.10	90.74
241.04	-120.08	170.44	-28.71
241.29	120.41	172.20	-148.97
2.59	-46.25	1.13	-156.01

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
9.19	3.69	19.22	93.68
10.57	17.92	21.71	108.64
12.20	-2.56	25.76	86.39
5.75	178.86	78.92	95.78

Cap

Figure 66: Measurement for load 2400Ω+j1602 (2uF)

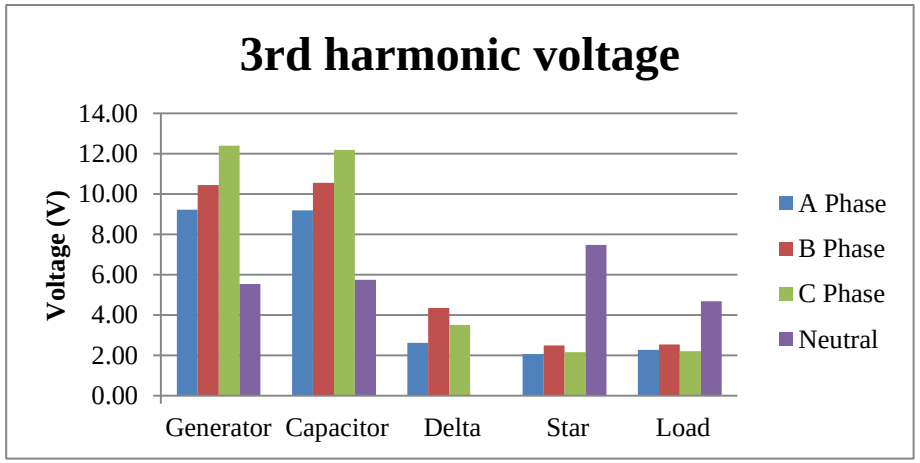


Figure 67: Third harmonic voltage for load 2400Ω+j1602 (2uF)

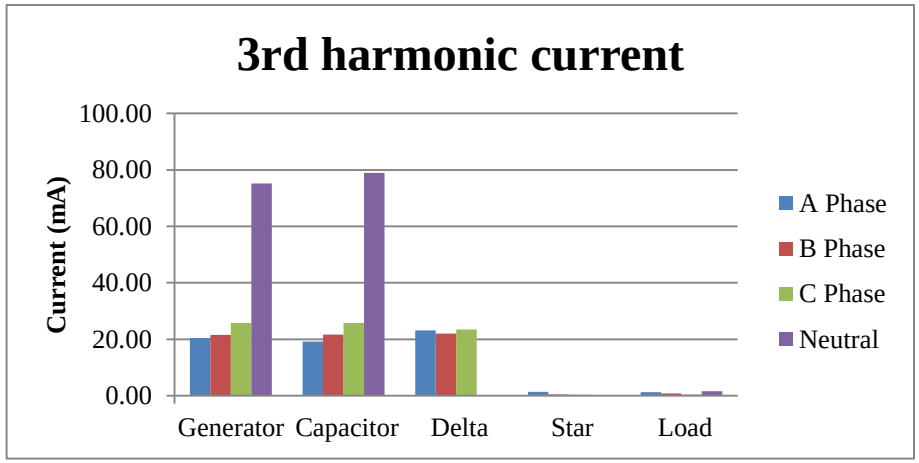


Figure 68: Third harmonic current for load 2400Ω+j1602 (2uF)

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
247.23	0.00	99.65	34.31
246.83	-120.05	99.47	-83.61
247.07	120.46	102.16	155.64
2.97	-85.03	1.08	-140.08

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
9.53	-3.58	19.93	90.87
10.24	9.84	20.48	99.50
12.85	-7.41	28.26	80.94
9.20	170.98	90.83	88.97

Gen

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
246.32	0.00	175.74	90.78
246.03	-120.07	174.04	-28.76
246.21	120.41	175.87	-148.98
3.10	-49.50	1.23	-150.83

Cap

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
9.46	-2.92	19.87	86.76
10.45	11.05	21.63	101.58
12.72	-7.51	26.68	81.33
5.63	172.65	73.75	89.27

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
430.97	-119.80	85.85	-53.19
429.98	120.26	81.87	-172.27
431.68	0.00	86.99	64.63
0.00	0.00	0.00	0.00

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
2.54	160.84	23.85	-44.67
4.22	29.74	23.30	-47.23
3.19	-113.25	24.29	-47.75
0.00	0.00	0.00	0.00

TX Delta

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
247.37	0.00	55.80	-30.57
246.89	-119.77	53.47	-149.28
247.96	120.25	53.37	89.43
2.55	-102.53	0.09	-134.55

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
1.85	165.25	1.12	113.98
2.29	34.94	0.22	75.42
2.18	-121.02	0.09	175.25
4.81	100.81	0.08	-178.45

TX Star

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
245.25	0.00	54.83	-29.14
244.71	-119.74	53.28	-149.76
245.96	120.23	52.85	89.73
1.74	-109.40	1.42	15.14

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
2.09	167.07	1.13	126.77
2.46	35.29	0.10	88.84
2.21	-117.29	0.11	121.79
4.72	101.67	1.12	92.05

Load

Figure 69: Measurement for load 3600Ω+j2388 (2uF)

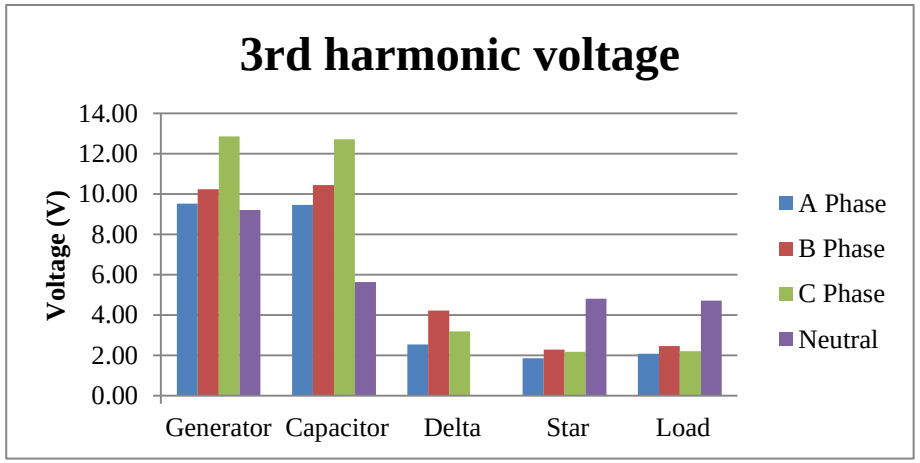


Figure 70: Third harmonic voltage for load 3600Ω+j2388 (2uF)

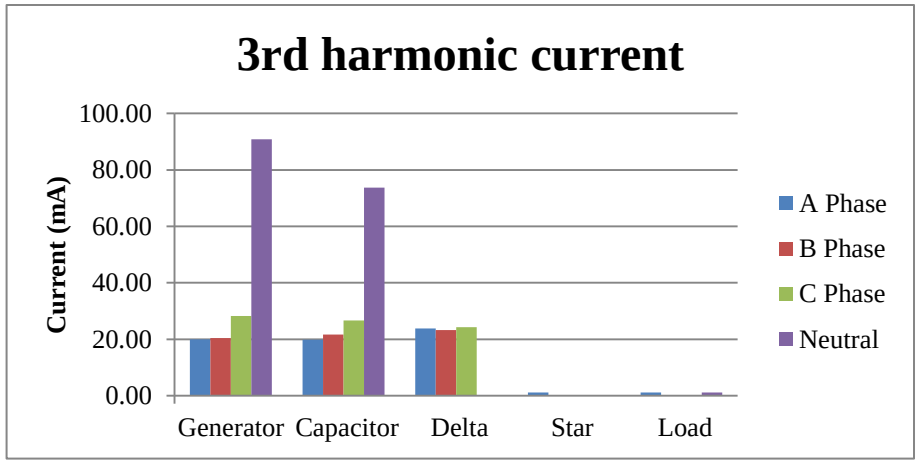


Figure 71: Third harmonic current for load 3600Ω+j2388 (2uF)

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
252.00	0.00	93.64	41.31
251.74	-120.02	93.87	-76.26
252.13	120.37	96.85	162.47
3.09	-74.65	0.99	-159.71

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
9.65	-7.18	21.21	88.89
10.66	6.31	21.76	93.70
13.01	-11.92	28.11	75.32
5.43	167.35	79.66	84.75

Gen

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
435.68	0.00	80.20	-57.12
434.94	-119.89	76.77	-175.79
436.37	120.20	81.35	61.68
0.00	0.00	0.00	0.00

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
2.18	152.98	24.85	-44.59
4.44	23.34	23.83	-46.90
3.59	-128.06	25.42	-47.16
0.00	0.00	0.00	0.00

TX Delta

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
250.97	0.00	180.23	90.68
250.85	-120.12	178.44	-28.82
250.99	120.32	180.32	-149.02
2.90	-55.98	1.30	-154.30

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
9.70	-5.20	20.23	84.28
10.87	6.51	22.44	96.37
12.72	-13.16	27.43	77.03
5.60	167.50	62.10	85.37

Cap

TX Star

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
248.17	0.00	39.85	-33.29
247.73	-119.76	39.02	-151.76
248.88	120.19	38.55	87.12
2.32	-115.17	0.12	-140.88

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
1.94	167.37	0.58	11.06
2.29	34.96	0.54	-14.94
2.10	-120.41	0.36	-162.96
4.48	95.19	0.14	87.93

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
250.70	0.00	40.44	-33.72
250.26	-119.83	39.02	-151.83
251.17	120.20	38.56	87.06
1.61	-126.80	0.23	19.54

Load

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
1.66	159.78	0.89	65.10
2.25	30.54	0.35	22.31
2.29	-129.12	0.23	-133.28
4.65	95.96	0.71	72.23

Figure 72: Measurement for load 4800Ω+j3581 (2uF)

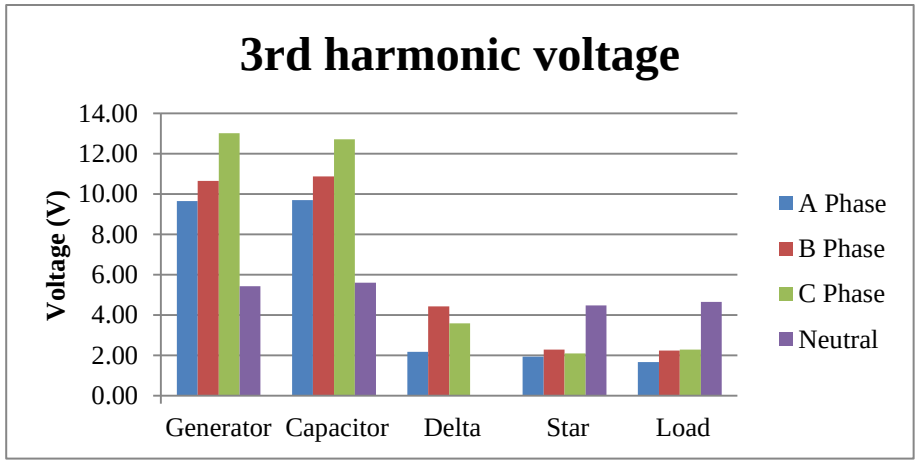


Figure 73: Third harmonic voltage for load 4800Ω+j3581 (2uF)

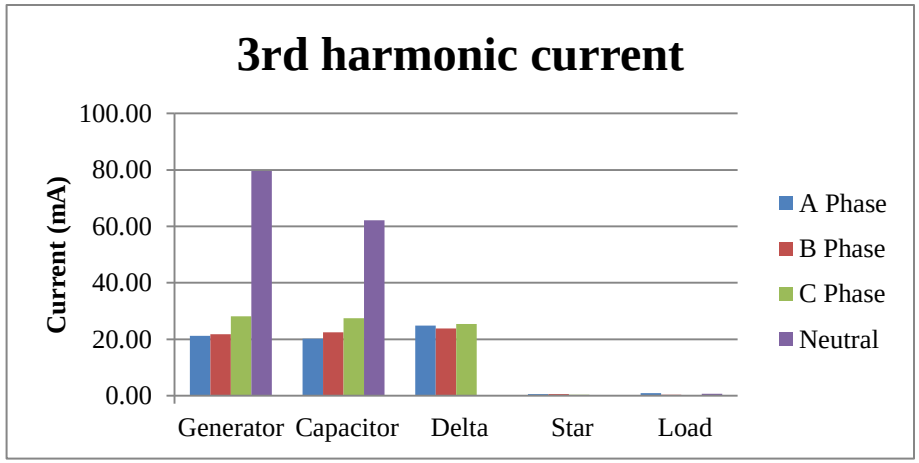


Figure 74: Third harmonic current for load 4800Ω+j3581 (2uF)

Appendix E: Generator Connected With Capacitor, Transformer and Load (2uF+0.55uF)

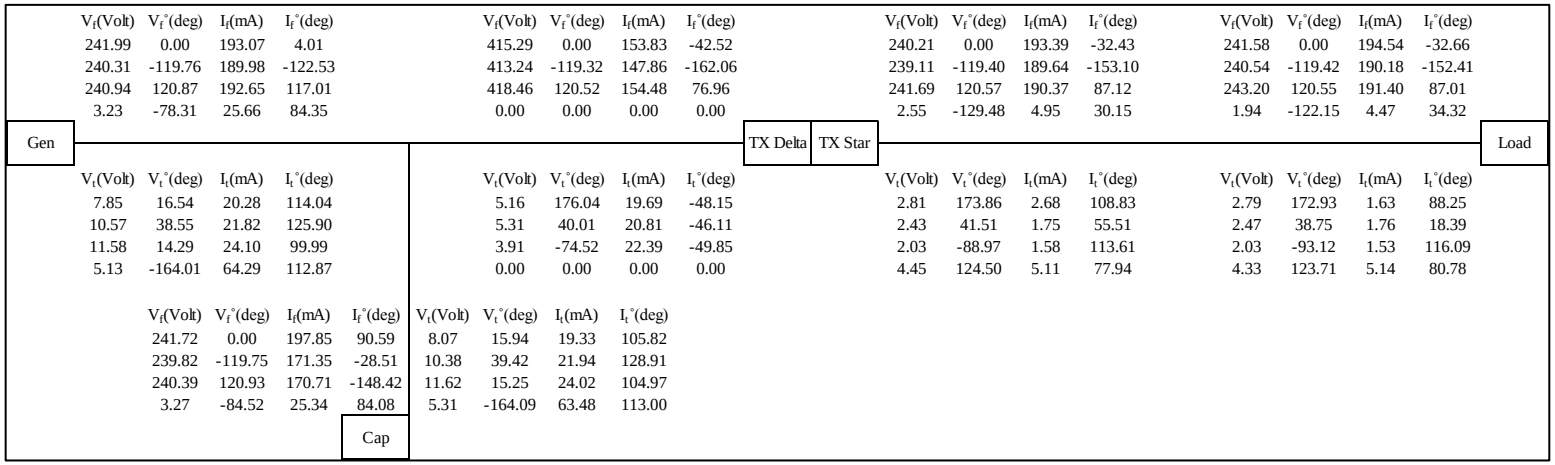


Figure 75: Measurement for load 960Ω+j660 (2uF+0.55uF)

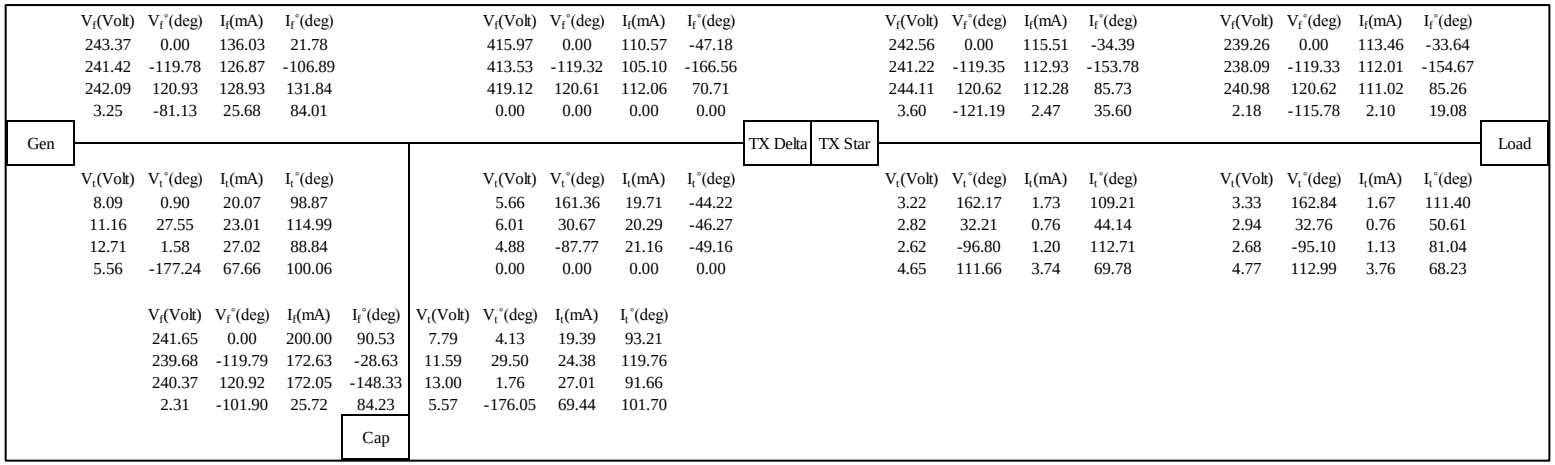


Figure 76: Measurement for load 1600Ω+j1194 (2uF+0.55uF)

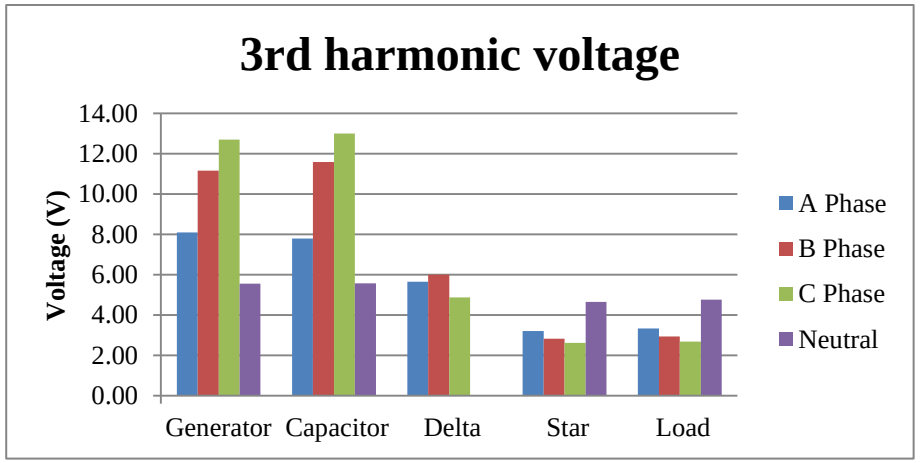


Figure 77: Third harmonic voltage for load 1600Ω+j1194 (2uF+0.55uF)

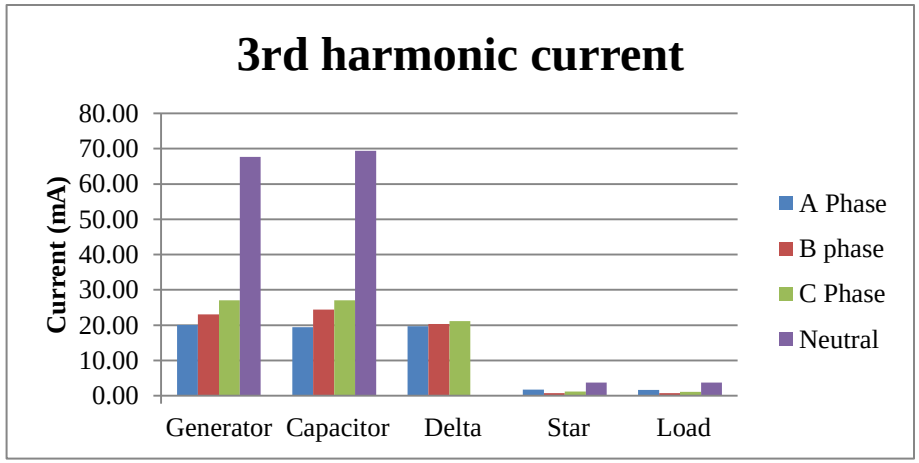


Figure 78: Third harmonic current for load 1600Ω+j1194 (2uF+0.55uF)

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
247.09	0.00	202.69	90.62
245.02	-119.75	175.40	-28.54
245.71	120.99	174.71	-148.36
2.88	-93.87	25.84	84.52

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
8.22	-3.33	19.57	86.88
11.03	24.10	23.27	113.18
12.72	-4.07	26.46	85.63
5.39	177.75	67.16	95.34

Gen

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
248.44	0.00	126.89	34.32
246.41	-119.76	113.09	-94.11
247.08	120.97	115.23	144.36
3.40	-79.53	26.12	84.26

Cap

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
8.19	-3.63	19.54	95.11
11.02	23.50	22.98	110.84
12.75	-4.45	27.47	82.73
5.40	177.09	67.47	94.89

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
427.05	0.00	97.34	-48.96
424.93	-119.40	92.11	-168.72
430.00	120.57	99.58	68.96
0.00	0.00	0.00	0.00

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
5.16	156.08	21.45	-43.84
5.94	23.97	22.03	-48.44
4.57	-98.85	23.13	-50.02
0.00	0.00	0.00	0.00

TX Delta

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
245.27	0.00	81.72	-29.45
244.03	-119.36	79.76	-149.79
247.06	120.58	80.01	90.37
4.63	-113.12	1.50	52.51

TX Star

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
3.24	159.70	1.39	131.18
3.01	26.43	0.48	118.75
2.63	-104.50	0.95	158.86
4.56	107.32	2.12	95.79

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
242.06	0.00	79.92	-29.22
240.80	-119.36	79.32	-150.57
243.71	120.58	78.21	90.34
3.13	-113.16	1.04	34.61

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
3.30	158.61	1.67	94.54
3.05	25.53	1.14	56.07
2.69	-104.75	0.48	-151.65
5.27	107.36	1.79	94.65

Load

Figure 79: Measurement for load 2400Ω+j1602 (2uF+0.55uF)

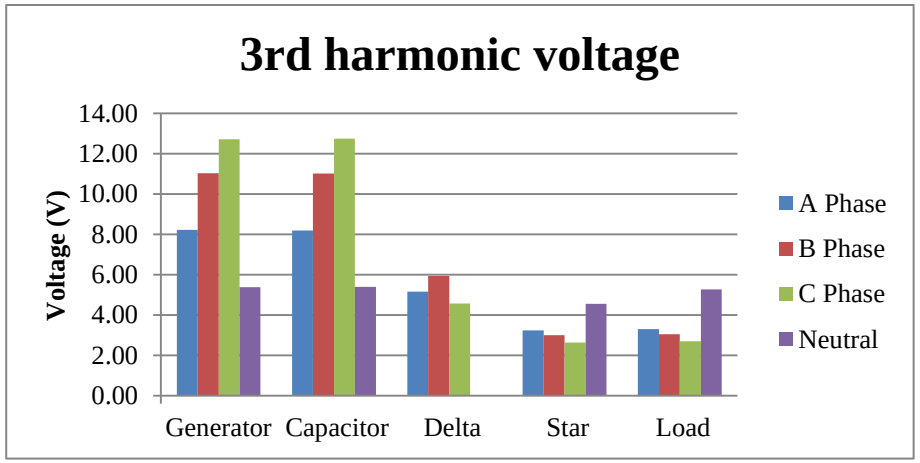


Figure 80: Third harmonic voltage for load 2400Ω+j1602 (2uF+0.55uF)

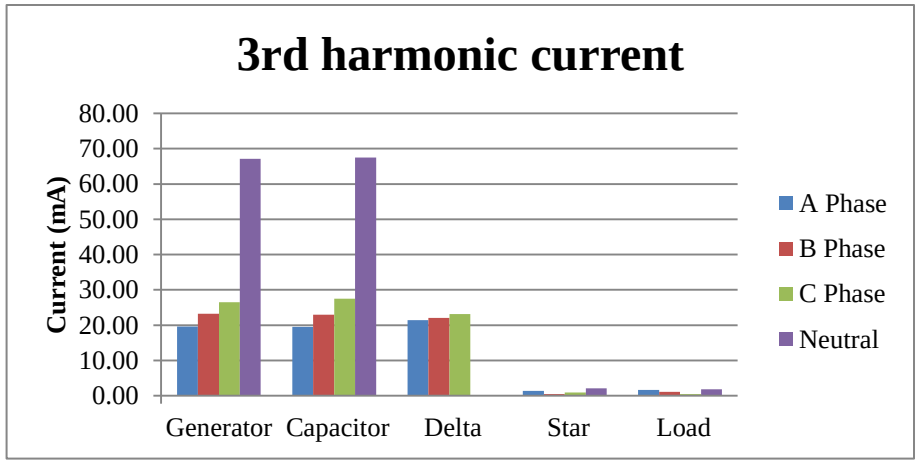


Figure 81: Third harmonic current for load 2400Ω+j1602 (2uF+0.55uF)

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
252.32	0.00	117.13	43.96
250.28	-119.79	100.84	-83.92
250.93	120.95	102.29	153.84
3.65	-78.63	26.42	84.41

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
435.33	0.00	87.71	-53.79
432.73	-119.35	83.02	-173.21
438.25	120.59	89.76	65.59
0.00	0.00	0.00	0.00

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
248.27	0.00	54.95	-28.91
247.25	-119.47	54.32	-150.19
250.10	120.46	54.07	90.47
4.04	-114.91	1.70	10.99

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
247.12	0.00	55.11	-28.58
245.61	-119.32	53.41	-150.11
248.66	120.67	52.55	90.54
3.53	-112.48	1.40	-7.79

Gen | TX Delta | TX Star | Load

Vt(Volt)	Vt°(deg)	It(mA)	It°(deg)
8.56	-9.59	20.50	86.18
10.99	16.52	22.50	103.82
13.02	-9.34	28.23	78.06
5.45	171.62	69.09	88.48

Vt(Volt)	Vt°(deg)	It(mA)	It°(deg)
5.12	155.21	24.00	-45.37
5.82	24.03	24.56	-48.01
4.56	-98.51	26.19	-48.25
0.00	0.00	0.00	0.00

Vt(Volt)	Vt°(deg)	It(mA)	It°(deg)
3.35	147.91	1.19	66.53
3.09	20.90	0.87	13.04
3.21	-111.50	0.35	90.28
4.55	99.32	0.87	98.16

Vt(Volt)	Vt°(deg)	It(mA)	It°(deg)
2.96	156.24	0.91	59.82
2.72	27.28	0.84	7.78
2.61	-106.46	0.53	-158.30
4.57	99.90	0.81	105.17

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
251.84	0.00	206.85	90.47
250.13	-119.87	178.64	-28.63
250.63	120.82	178.06	-148.43
3.02	-91.34	26.56	84.19

Vt(Volt)	Vt°(deg)	It(mA)	It°(deg)
8.45	-7.42	20.28	80.88
11.21	15.61	23.43	105.48
12.88	-10.92	26.81	79.61
5.46	170.70	68.77	88.39

Cap

Figure 82: Measurement for load 3600Ω+j2388 (2uF+0.55uF)

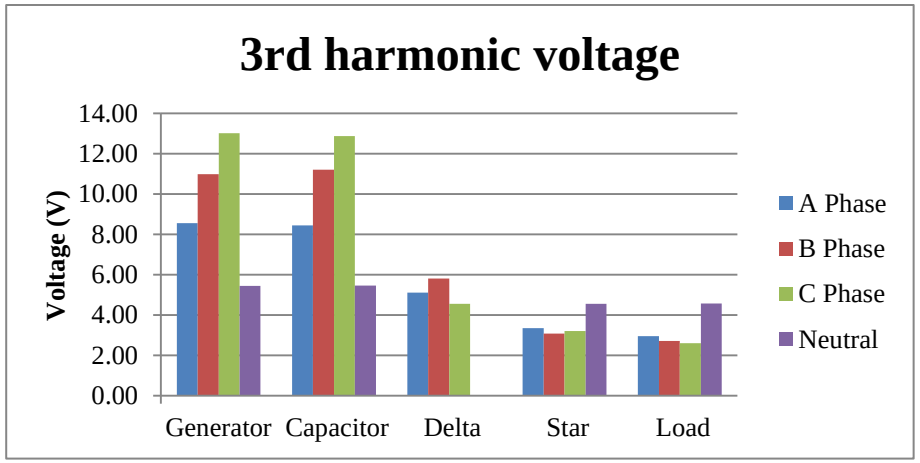


Figure 83: Third harmonic voltage for load 3600Ω+j2388 (2uF+0.55uF)

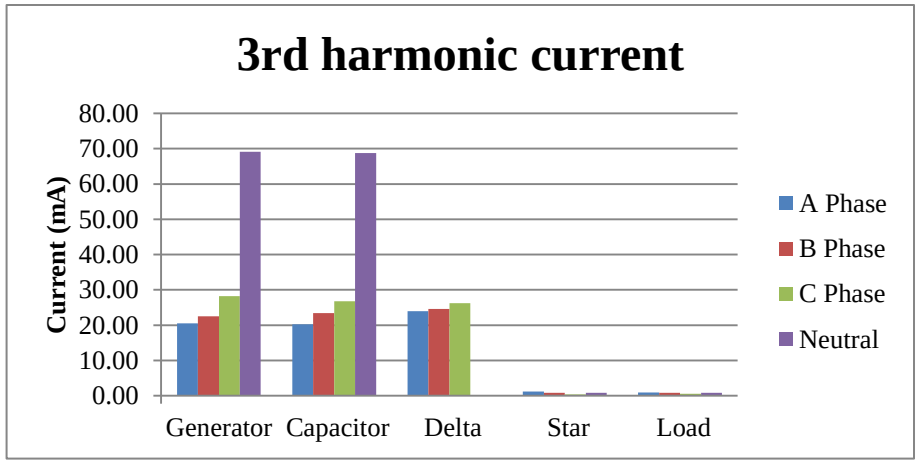


Figure 84: Third harmonic current for load 3600Ω+j2388 (2uF+0.55uF)

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
253.86	0.00	110.96	49.85
252.03	-119.87	93.03	-77.14
252.41	120.93	94.37	160.16
3.57	-82.98	26.48	84.49

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
438.09	0.00	82.45	-57.71
435.98	-119.40	78.19	-176.69
441.27	120.52	84.47	62.07
0.00	0.00	0.00	0.00

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
252.43	0.00	40.59	-33.71
250.97	-119.36	39.94	-151.94
254.06	120.62	38.81	89.06
3.66	-120.49	0.49	38.71

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
253.55	0.00	40.36	-31.25
252.09	-119.38	39.91	-152.48
254.98	120.62	38.60	88.87
3.51	-117.55	0.28	-74.72

Gen | TX Delta | TX Star | Load

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
8.78	-12.02	20.27	83.98
11.22	10.17	22.73	98.67
12.94	-12.45	28.47	75.56
5.34	165.68	70.44	84.85

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
5.06	149.38	25.12	-44.57
5.54	19.32	25.54	-47.06
4.50	-101.48	27.06	-46.90
0.00	0.00	0.00	0.00

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
2.95	153.61	0.93	48.43
2.76	23.54	0.71	5.03
2.68	-111.23	0.28	40.24
4.56	95.19	0.33	93.08

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
3.05	152.27	0.39	-59.39
2.77	19.18	0.74	-77.44
2.63	-112.45	0.50	154.15
4.50	96.08	0.70	98.21

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
253.44	0.00	207.41	90.51
251.82	-119.86	179.18	-28.60
252.28	120.84	178.57	-148.42
3.34	-95.73	26.63	84.15

Cap

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
8.74	-11.85	20.99	77.11
11.28	11.28	23.45	101.06
13.08	-13.79	27.11	76.32
5.35	166.89	70.92	84.76

Figure 85: Measurement for load 4800Ω+j3581 (2uF+0.55uF)

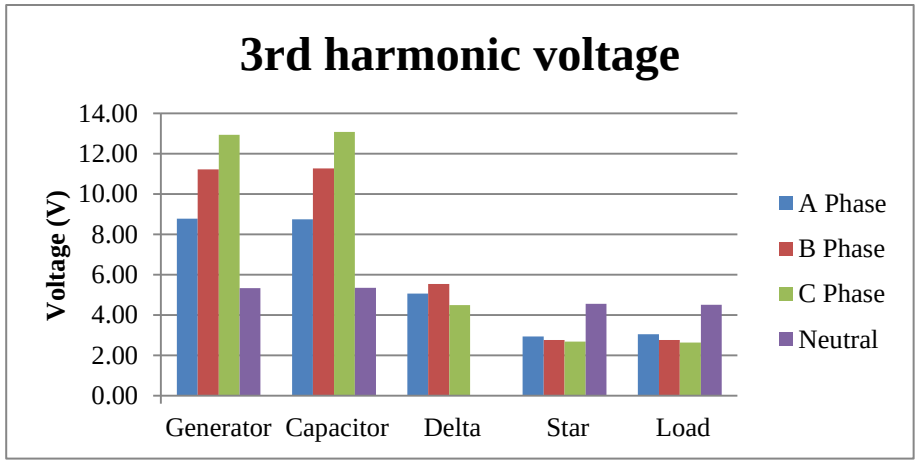


Figure 86: Third harmonic voltage for load 4800Ω+j3581 (2uF+0.55uF)

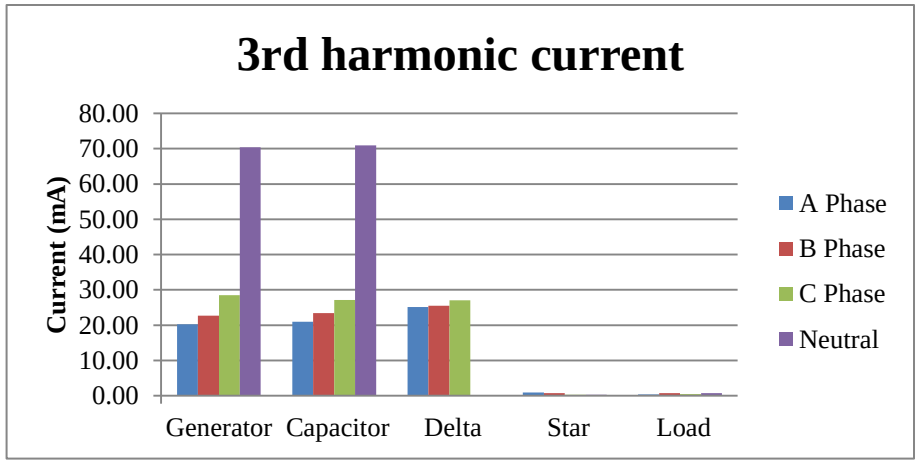


Figure 87: Third harmonic current for load 4800Ω+j3581 (2uF+0.55uF)

Appendix F: Generator Connected With Capacitor, Transformer and Load (2uF+1uF)

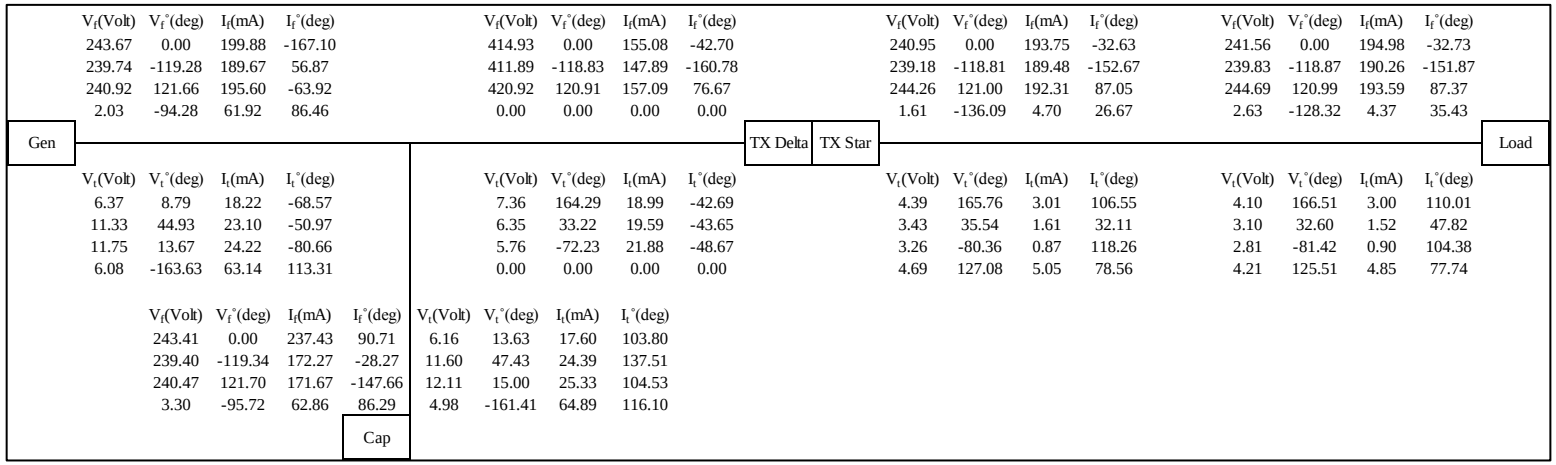


Figure 88: Measurement for load 960Ω+j660 (2uF+1uF)

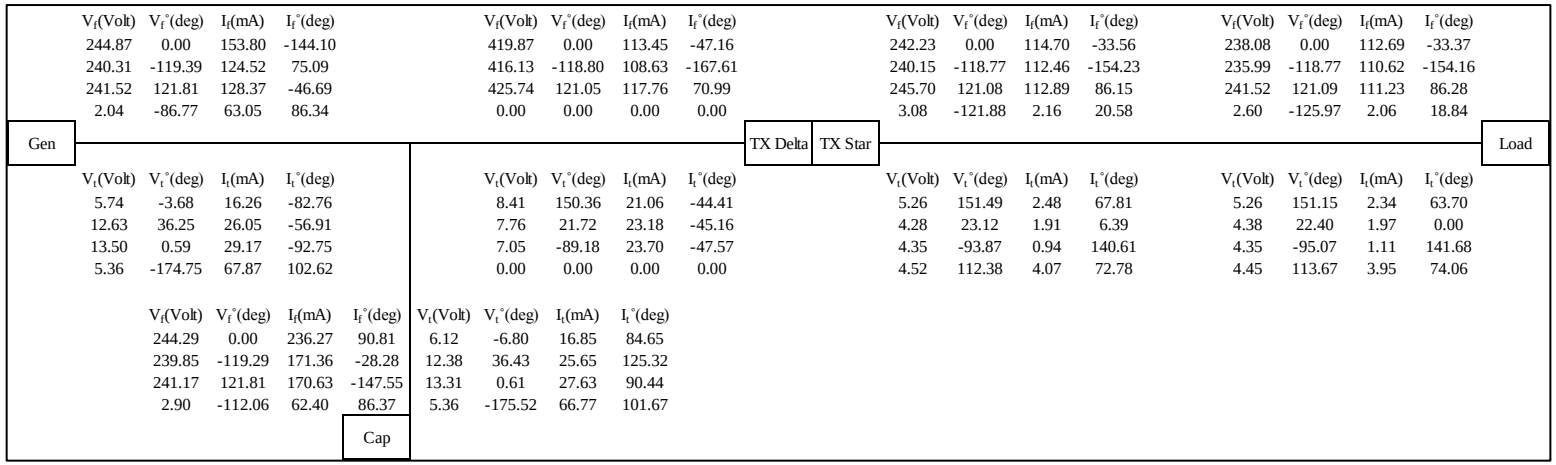


Figure 89: Measurement for load 1600Ω+j1194 (2uF+1uF)

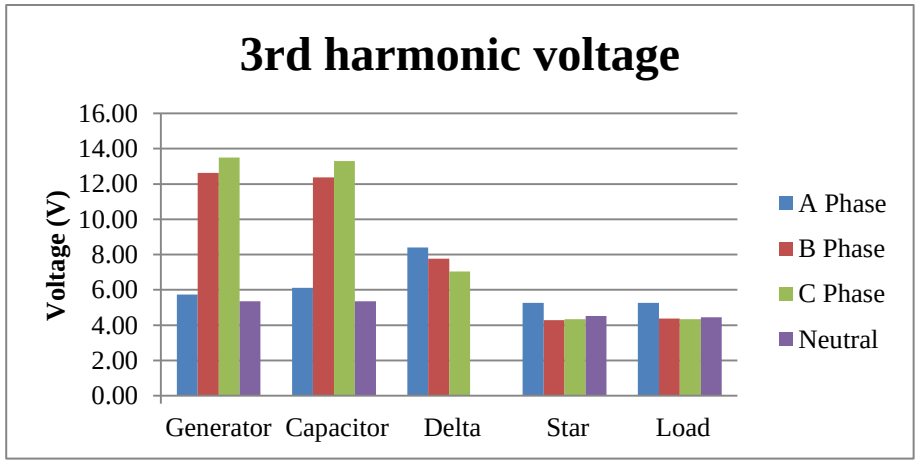


Figure 90: Third harmonic voltage for load 1600Ω+j1194 (2uF+1uF)

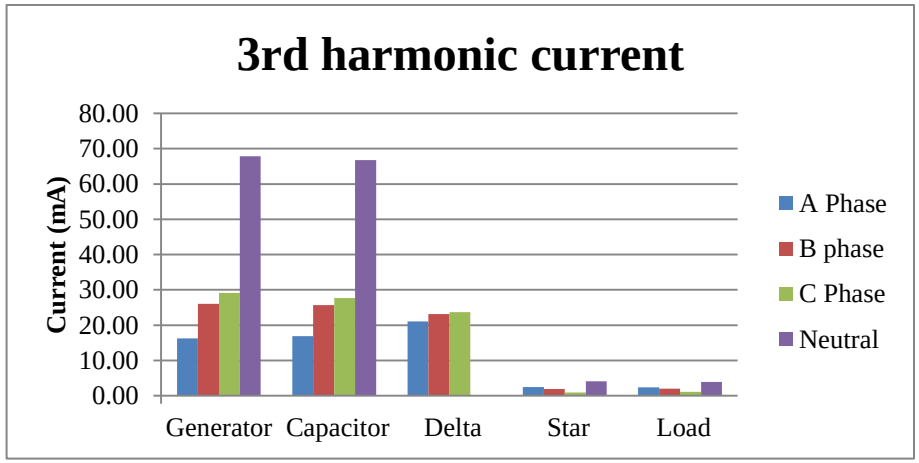


Figure 91: Third harmonic current for load 1600Ω+j1194 (2uF+1uF)

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
248.25	0.00	148.08	-134.81
244.03	-119.39	110.43	85.41
245.27	121.74	114.38	-36.83
2.30	-81.92	63.24	86.43

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
6.07	-10.53	16.37	-89.69
12.36	30.26	25.18	-61.81
13.20	-6.25	28.36	-101.48
5.15	178.62	66.91	95.73

Gen

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
429.92	0.00	100.31	-50.06
425.91	-118.77	93.81	-167.45
436.01	121.04	103.57	69.07
0.00	0.00	0.00	0.00

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
8.71	146.60	21.80	-43.26
7.96	16.75	22.87	-47.95
7.10	-92.85	25.11	-49.43
0.00	0.00	0.00	0.00

TX Delta

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
251.32	0.00	243.64	90.69
246.97	-119.40	176.55	-28.33
248.17	121.74	176.05	-147.59
3.43	-102.58	64.33	86.37

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
6.01	-10.22	16.91	79.33
12.45	29.90	25.96	119.88
13.24	-6.93	27.62	82.86
5.32	178.70	67.14	95.45

Cap

TX Star

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
245.77	0.00	81.61	-30.02
243.70	-118.76	80.66	-149.94
249.23	121.06	81.05	90.41
2.35	-121.26	1.33	34.53

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
5.32	148.87	0.83	119.58
4.32	18.03	0.44	-74.31
4.22	-97.92	0.62	158.30
4.49	108.69	2.13	97.79

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
244.91	0.00	81.30	-29.73
242.89	-118.73	80.51	-149.99
248.55	121.05	80.97	90.46
3.12	-120.22	1.24	30.91

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
5.43	149.66	1.33	129.05
4.35	18.22	0.16	-163.47
4.23	-96.36	0.37	168.17
4.43	109.04	2.23	93.58

Load

Figure 92: Measurement for load 2400Ω+j1602 (2uF+1uF)

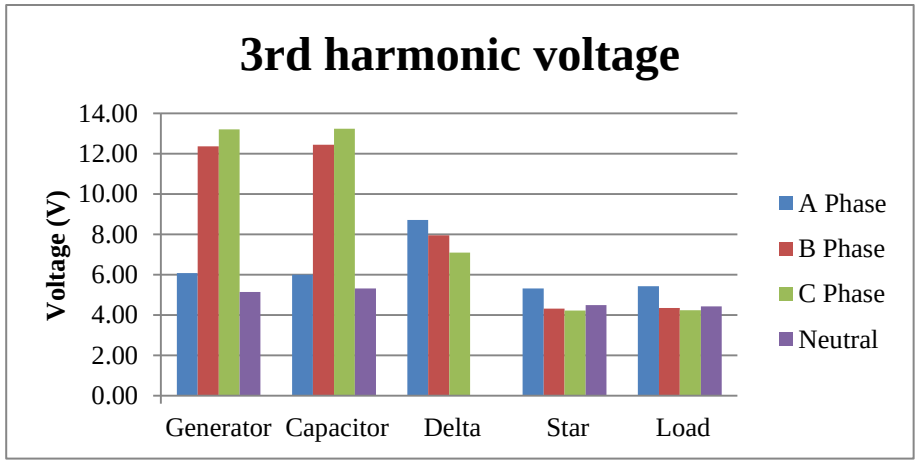


Figure 93: Third harmonic voltage for load 2400Ω+j1602 (2uF+1uF)

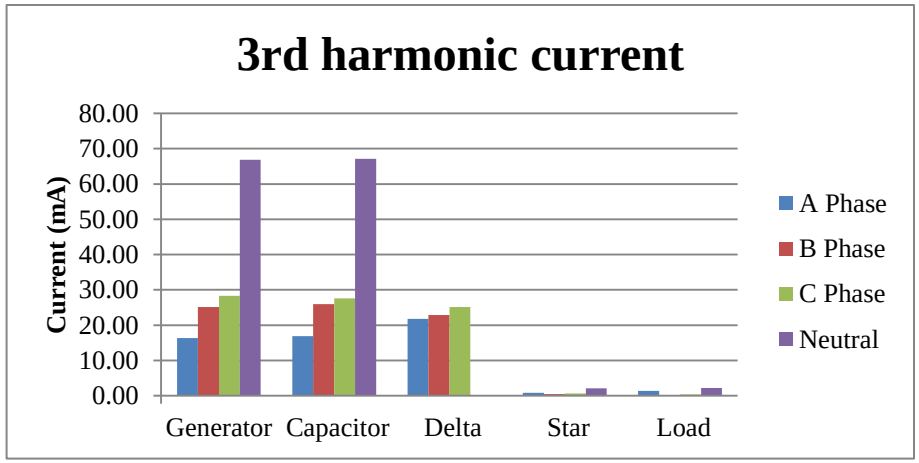


Figure 94: Third harmonic current for load 2400Ω+j1602 (2uF+1uF)

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
256.38	0.00	145.16	-125.83
251.83	-119.40	99.67	95.51
253.14	121.75	102.36	-27.65
2.85	-80.49	65.62	86.39

Vt(Volt)	Vt°(deg)	It(mA)	It°(deg)
6.31	-18.22	16.54	-98.73
12.49	23.92	25.20	-69.39
13.65	-12.06	30.37	-104.60
5.30	171.16	68.93	89.13

Gen

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
254.43	0.00	245.78	90.68
250.10	-119.45	178.13	-28.36
251.22	121.69	177.62	-147.62
3.33	-104.70	64.85	86.44

Cap

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
440.36	0.00	90.09	-54.14
435.93	-118.65	84.54	-172.22
446.41	121.17	94.26	65.27
0.00	0.00	0.00	0.00

Vt(Volt)	Vt°(deg)	It(mA)	It°(deg)
8.37	143.22	24.65	-40.97
7.65	18.23	24.42	-43.00
7.37	-94.06	26.92	-44.59
0.00	0.00	0.00	0.00

Vt(Volt)	Vt°(deg)	It(mA)	It°(deg)
6.30	-16.42	17.58	72.62
12.57	23.63	26.07	113.53
13.49	-12.72	28.09	77.31
5.28	172.50	68.46	89.10

TX Delta

TX Star

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
250.61	0.00	56.52	-30.38
248.20	-118.77	54.48	-147.98
254.13	121.07	55.11	90.69
3.48	-117.71	1.40	20.60

Vt(Volt)	Vt°(deg)	It(mA)	It°(deg)
5.31	144.06	0.83	144.60
4.27	12.54	0.50	-131.55
4.27	-102.96	0.20	140.21
4.37	101.95	1.02	87.14

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
249.36	0.00	55.43	-30.18
247.20	-118.75	55.51	-149.06
252.90	121.07	54.98	90.00
3.33	-118.49	1.75	7.15

Vt(Volt)	Vt°(deg)	It(mA)	It°(deg)
5.24	145.73	1.15	59.53
4.22	14.18	1.06	-6.39
4.18	-101.46	0.78	-166.98
4.42	100.35	0.81	112.84

Load

Figure 95: Measurement for load 3600Ω+j2388 (2uF+1uF)

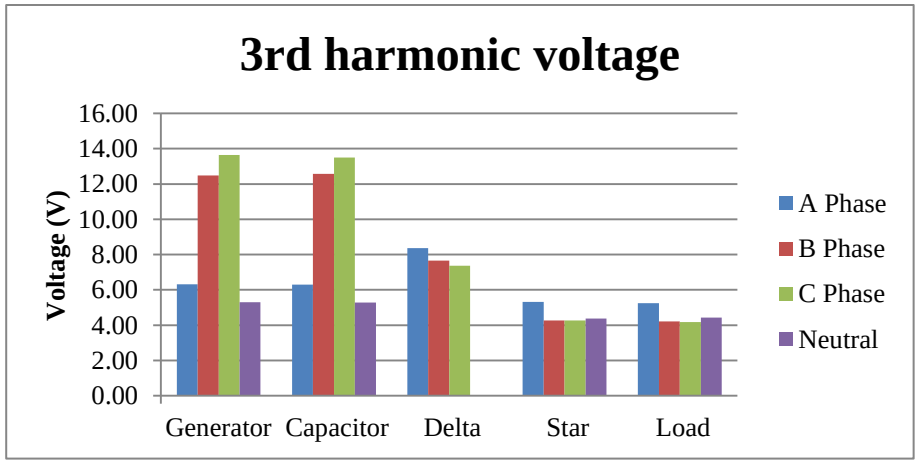


Figure 96: Third harmonic voltage for load 3600Ω+j2388 (2uF+1uF)

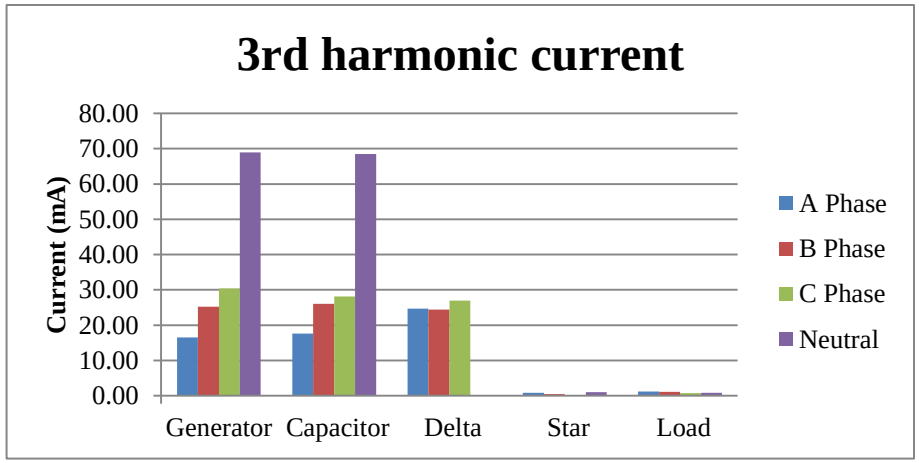


Figure 97: Third harmonic current for load 3600Ω+j2388 (2uF+1uF)

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
258.94	0.00	141.68	-120.64
254.64	-119.43	91.99	101.96
255.96	121.63	94.19	-21.76
2.38	-88.37	66.44	86.41

Vt(Volt)	Vt°(deg)	It(mA)	It°(deg)
6.36	-19.24	17.43	-102.39
12.75	18.89	25.45	-74.57
13.84	-16.74	30.12	-106.65
5.21	167.35	70.20	85.07

Gen

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
439.64	0.00	84.05	-57.67
435.85	-118.73	78.25	-174.93
445.99	121.07	87.49	61.46
0.00	0.00	0.00	0.00

Vt(Volt)	Vt°(deg)	It(mA)	It°(deg)
8.64	140.35	24.05	-42.32
7.66	10.63	24.93	-47.62
7.00	-97.09	27.18	-47.21
0.00	0.00	0.00	0.00

TX Delta

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
253.18	0.00	40.91	-32.92
251.09	-118.79	39.62	-149.82
256.69	121.05	39.79	89.36
2.93	-126.99	0.33	78.73

Vt(Volt)	Vt°(deg)	It(mA)	It°(deg)
5.24	141.27	0.29	-19.58
4.28	9.00	0.85	-75.33
4.27	-107.11	0.40	151.88
4.24	96.69	0.55	100.36

TX Star

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
252.97	0.00	40.57	-33.06
250.82	-118.74	40.54	-152.06
256.64	121.02	40.17	87.68
3.28	-125.26	0.42	-7.25

Vt(Volt)	Vt°(deg)	It(mA)	It°(deg)
5.45	144.49	0.56	9.13
4.34	10.69	0.97	-50.14
4.22	-103.17	0.51	172.05
4.35	96.09	0.48	107.50

Load

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
257.89	0.00	249.78	90.74
253.51	-119.41	181.09	-28.34
254.74	121.74	180.51	-147.62
3.06	-111.36	65.88	86.50

Cap

Vt(Volt)	Vt°(deg)	It(mA)	It°(deg)
6.71	-21.04	18.83	69.11
12.63	19.36	26.37	109.33
13.71	-15.19	28.57	74.24
5.15	168.28	70.80	85.37

Figure 98: Measurement for load 4800Ω+j3581 (2uF+1uF)

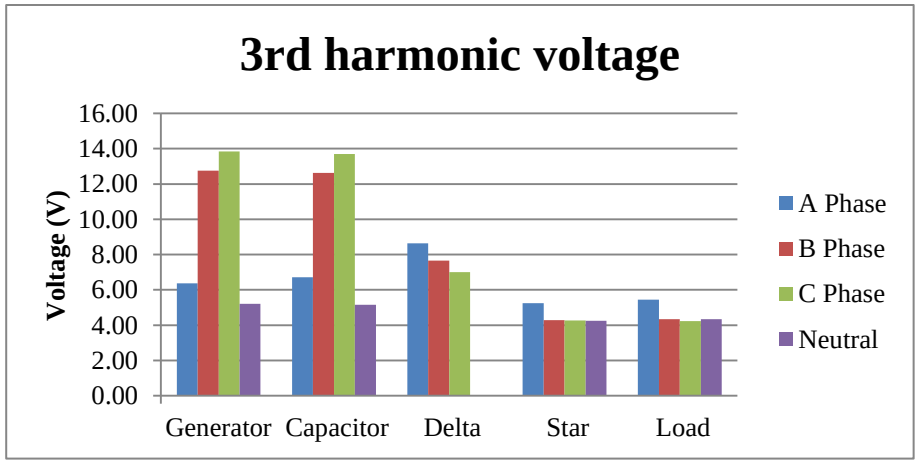


Figure 99: Third harmonic voltage for load 4800Ω+j3581 (2uF+1uF)

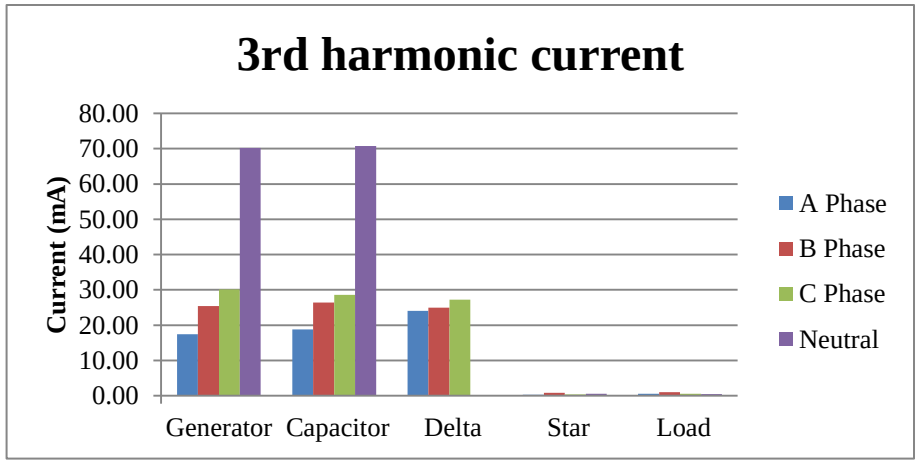


Figure 100: Third harmonic current for load 4800Ω+j3581 (2uF+1uF)

Appendix G: Generator Connected With Capacitor, Transformer and Load (1uF)

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
239.10	0.00	211.99	-42.58
238.80	-119.94	211.58	-163.03
239.44	120.36	209.35	77.43
1.17	-38.39	1.55	121.04

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
416.00	0.00	158.17	-53.92
415.47	-119.74	152.65	-175.10
417.10	120.21	157.08	65.23
0.00	0.00	0.00	0.00

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
240.17	0.00	195.12	-49.58
240.12	-119.73	190.16	-169.97
241.03	120.16	190.84	70.02
2.05	-99.00	0.22	34.69

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
239.55	0.00	192.95	-49.29
239.59	-119.74	188.15	-170.18
240.36	120.16	188.82	69.96
2.74	-76.84	3.99	10.96

Gen — TX Delta — TX Star — Load

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
11.69	5.07	11.36	101.82
12.23	9.98	11.91	93.81
13.57	1.06	13.13	86.85
6.46	177.89	35.44	94.80

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
1.07	156.96	20.50	-44.43
2.15	43.61	20.27	-48.48
1.93	-107.30	21.55	-48.22
0.00	0.00	0.00	0.00

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
0.94	177.87	3.07	27.30
1.11	57.27	4.04	9.46
1.36	-124.93	3.10	16.49
5.37	102.35	0.15	138.90

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
1.01	172.94	2.70	36.07
1.09	55.03	3.89	9.54
1.35	-121.76	3.11	19.07
5.47	104.04	8.69	18.59

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
240.74	0.00	79.23	90.99
240.40	-119.85	76.99	-28.70
241.02	120.44	78.44	-148.96
0.61	-56.60	1.68	115.15

Cap

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
11.80	3.82	11.46	94.24
11.94	10.92	11.35	99.47
13.60	1.41	12.92	91.52
7.17	176.83	39.75	95.12

Figure 101: Measurement for load 960Ω+j358 (1uF)

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
240.68	0.00	143.44	-28.27
240.54	-120.04	143.26	-148.18
240.81	120.32	143.58	92.10
3.26	-50.27	1.62	120.50

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
416.94	0.00	112.12	-48.04
416.22	-119.77	107.03	-166.77
417.98	120.19	111.86	70.52
0.00	0.00	0.00	0.00

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
240.48	0.00	114.56	-33.09
240.05	-119.77	111.61	-154.46
241.13	120.22	111.19	85.56
3.47	-91.54	0.29	-123.84

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
239.47	0.00	113.52	-33.42
239.07	-119.77	111.30	-154.63
240.00	120.22	110.45	85.28
1.48	-99.25	2.07	13.07

Gen — TX Delta — TX Star — Load

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
11.05	2.86	10.99	100.59
11.09	10.83	10.22	104.94
12.96	0.00	13.14	84.22
6.00	176.40	34.81	93.99

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
1.75	-177.27	19.93	-47.48
3.16	44.71	20.41	-52.22
2.20	-103.05	21.67	-52.37
0.00	0.00	0.00	0.00

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
1.22	-174.24	0.53	50.45
1.46	52.44	1.14	20.16
1.29	-118.87	1.01	85.49
5.01	104.77	0.13	56.08

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
1.27	-176.22	1.07	120.26
1.50	50.79	0.76	51.90
1.31	-117.31	1.17	89.82
6.51	107.71	2.81	77.20

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
241.14	0.00	79.78	90.93
241.03	-120.03	77.28	-28.81
241.24	120.33	78.76	-148.98
3.66	-51.71	1.76	121.13

Cap

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
11.17	3.81	10.96	93.67
11.35	11.78	10.61	101.79
13.09	0.00	12.56	90.37
6.45	178.82	33.53	94.64

Figure 102: Measurement for load 1600Ω+j1194 (1uF)

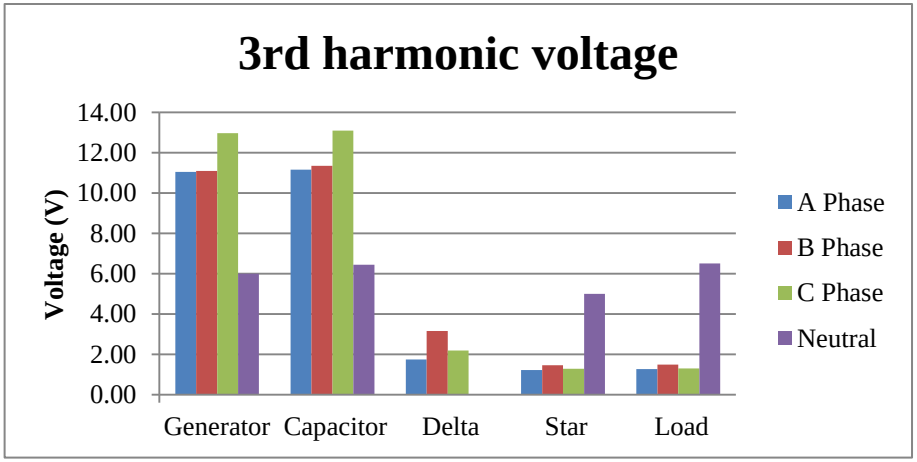


Figure 103: Third harmonic voltage for load 1600Ω+j1194 (1uF)

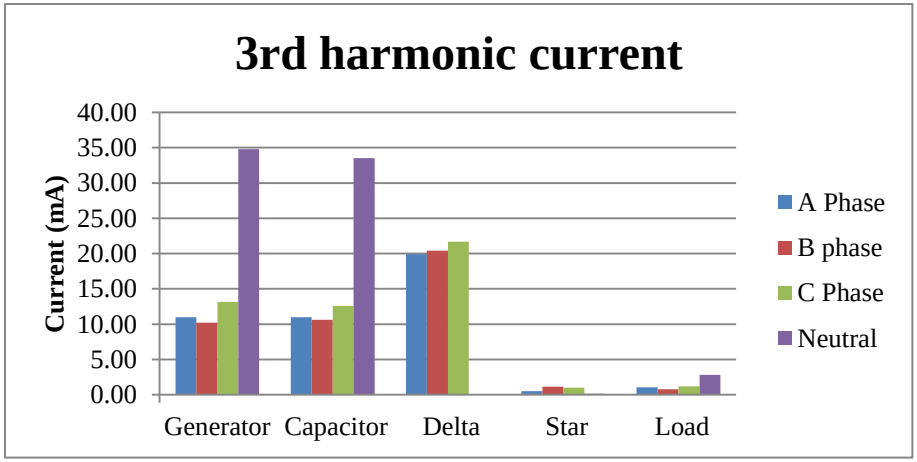


Figure 104: Third harmonic current for load 1600Ω+j1194 (1uF)

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
241.06	0.00	110.98	-23.24
240.77	-120.02	109.72	-143.18
241.00	120.41	110.84	97.53
3.97	-51.49	1.61	120.11

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
418.24	0.00	94.16	-48.91
417.45	-119.81	88.74	-168.42
418.98	120.21	94.82	69.04
0.00	0.00	0.00	0.00

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
239.32	0.00	79.53	-29.82
239.08	-119.80	77.94	-150.75
239.89	120.19	77.62	89.81
3.87	-88.17	0.31	-20.84

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
241.43	0.00	80.25	-29.70
241.16	-119.75	78.44	-150.74
242.03	120.24	78.30	89.95
3.38	-86.61	0.88	65.84

Gen | TX Delta | TX Star | Load

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
11.41	-0.68	10.97	97.27
11.02	7.24	9.33	91.14
13.13	-2.71	13.27	81.62
6.23	174.04	34.14	90.80

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
1.51	-174.30	21.55	-46.24
2.80	36.85	20.61	-48.43
1.71	-115.71	22.08	-49.30
0.00	0.00	0.00	0.00

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
1.31	-176.50	0.99	156.61
1.61	44.27	0.43	120.85
1.31	-125.39	0.57	136.70
5.27	104.05	0.13	-40.00

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
1.42	-169.49	1.18	140.50
1.54	46.95	0.66	107.38
1.15	-124.40	0.62	127.50
5.07	103.87	2.22	106.96

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
240.77	0.00	79.59	90.90
240.74	-120.08	77.10	-28.83
240.88	120.29	78.63	-149.02
3.96	-50.70	1.73	132.10

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
11.43	0.60	11.13	90.23
11.44	8.12	10.67	98.22
12.93	-3.60	12.58	86.50
6.42	174.47	33.20	90.99

Cap

Figure 105: Measurement for load 2400Ω+j1602 (1uF)

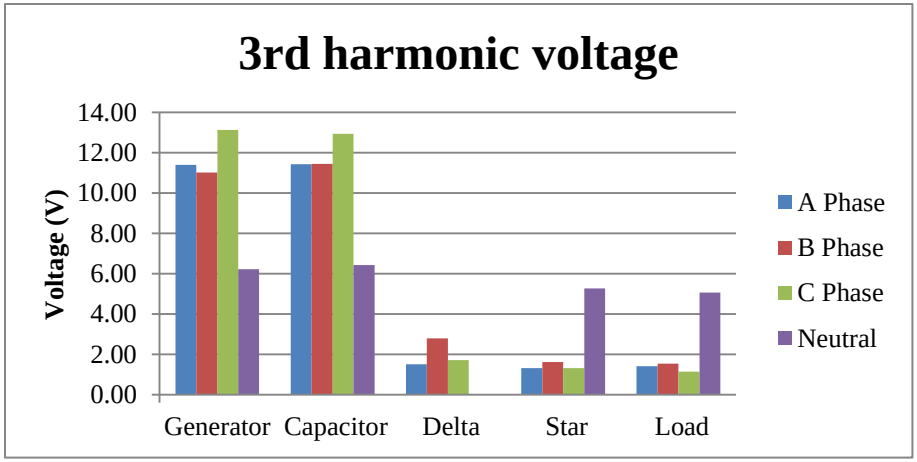


Figure 106: Third harmonic voltage for load 2400Ω+j1602 (1uF)

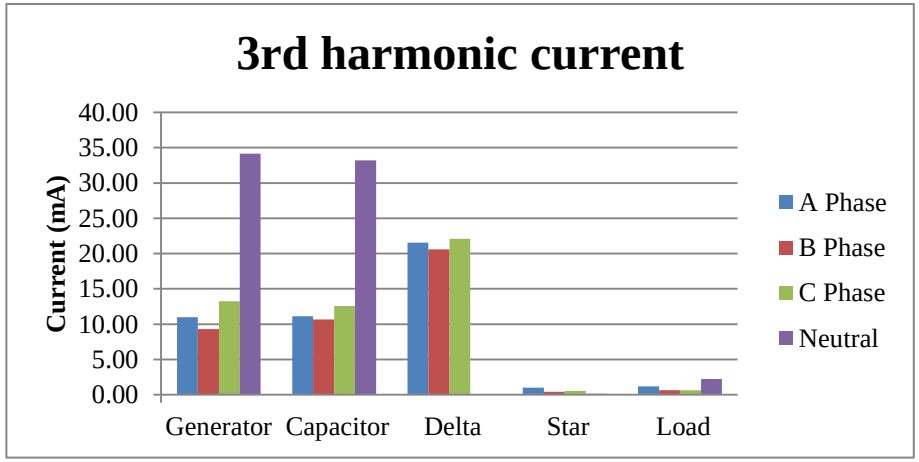


Figure 107: Third harmonic current for load 2300Ω+j1602 (1uF)

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
241.04	0.00	95.50	-10.19
240.97	-120.05	94.03	-129.28
241.13	120.30	96.64	111.12
3.49	-57.58	1.64	119.24

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
417.95	0.00	77.80	-51.78
417.06	-119.75	73.42	-172.50
419.02	120.19	78.53	65.97
0.00	0.00	0.00	0.00

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
240.14	0.00	53.94	-30.50
239.59	-119.78	52.09	-149.36
240.54	120.23	51.71	89.65
3.63	-91.77	0.26	54.85

Vf(Volt)	Vf°(deg)	If(mA)	If°(deg)
240.57	0.00	53.70	-30.40
240.27	-119.85	51.90	-149.89
241.04	120.17	51.68	89.40
4.08	-83.72	1.42	-39.24

Gen | TX Delta | TX Star | Load

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
11.03	0.55	11.37	99.50
11.07	9.86	10.10	102.57
12.99	-3.01	13.36	80.74
5.78	174.49	33.43	91.85

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
2.02	-172.69	20.42	-49.62
3.30	36.45	21.25	-53.10
1.85	-112.30	21.85	-53.28
0.00	0.00	0.00	0.00

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
1.16	-178.16	1.02	123.58
1.39	44.69	0.39	113.44
1.22	-128.21	0.38	110.00
5.19	98.79	0.08	-160.35

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
1.20	-178.74	0.60	30.07
1.58	39.32	0.42	-8.16
1.40	-133.81	0.27	134.48
5.34	98.22	1.82	83.93

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
240.37	0.00	79.42	90.93
240.29	-120.09	76.96	-28.83
240.41	120.36	78.41	-149.03
3.27	-55.43	1.69	127.22

Cap

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
11.14	0.33	10.91	90.23
10.86	8.49	10.17	99.63
12.83	-1.55	12.27	87.28
5.86	175.41	33.22	91.60

Figure 108: Measurement for load 3600Ω+j2388 (1uF)

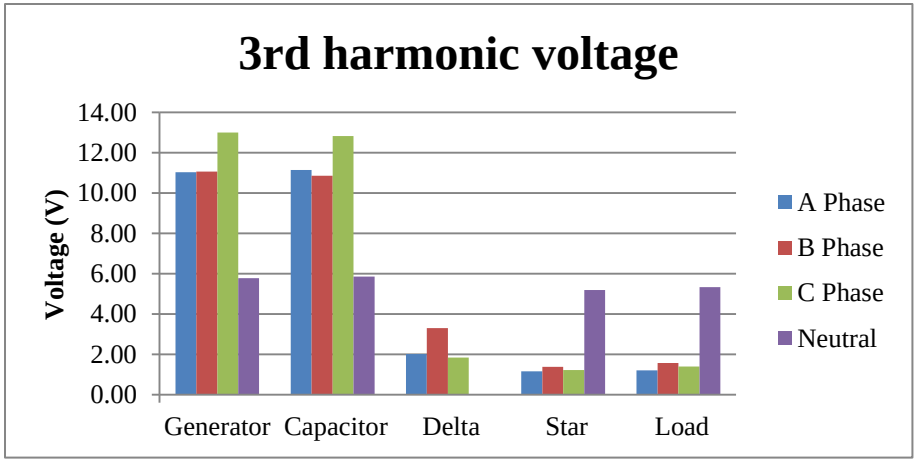


Figure 109: Third harmonic voltage for load 3600Ω+j2388 (1uF)

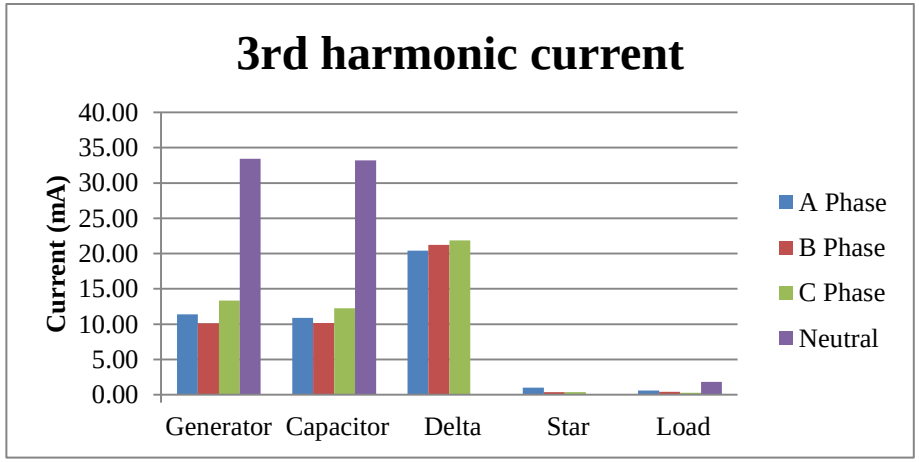


Figure 110: Third harmonic current for load 3600Ω+j2388 (1uF)

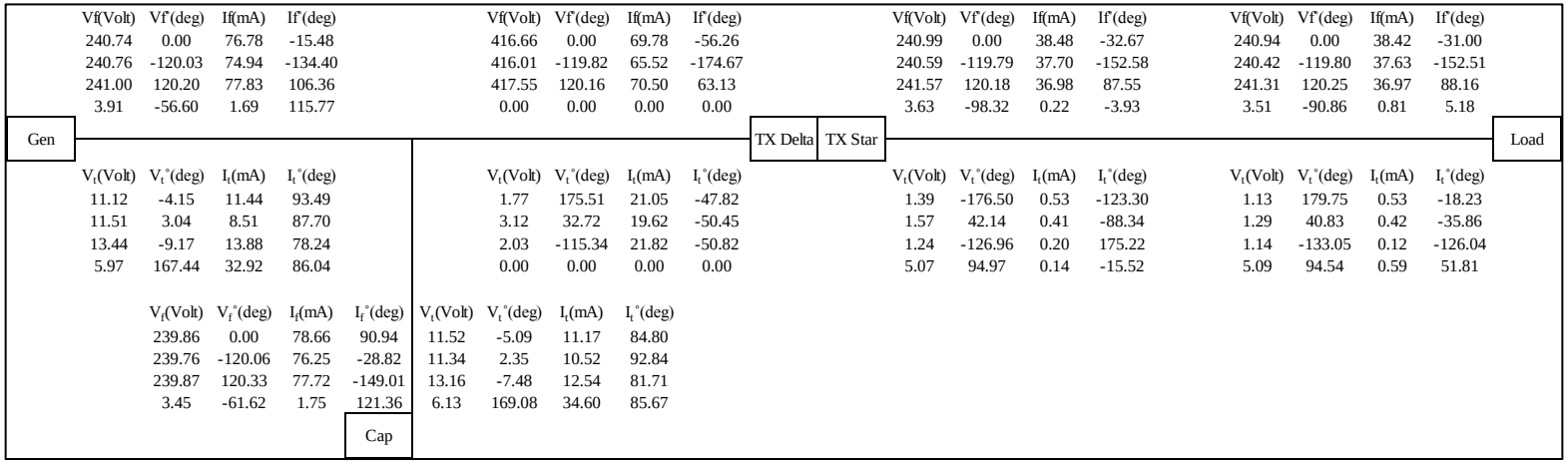


Figure 111: Measurement for load 4800Ω+j3581 (1uF)

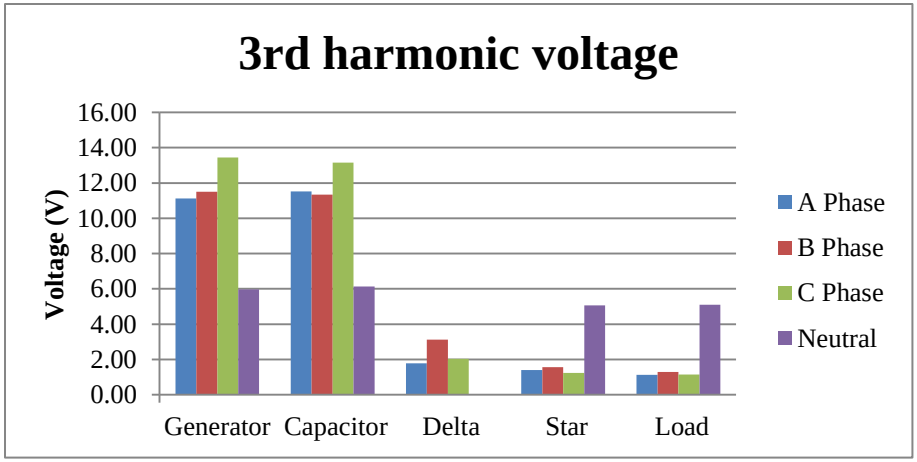


Figure 112: Third harmonic voltage for load 4800Ω+j3581 (1uF)

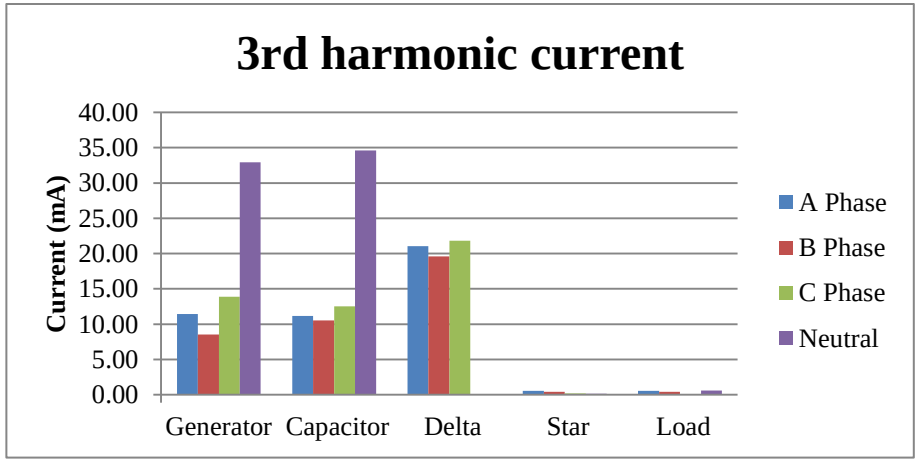


Figure 113: Third harmonic current for load 4800Ω+j3581 (1uF)

Appendix H: Generator Connected With Capacitor, Transformer and Load (1uF+0.22uF)

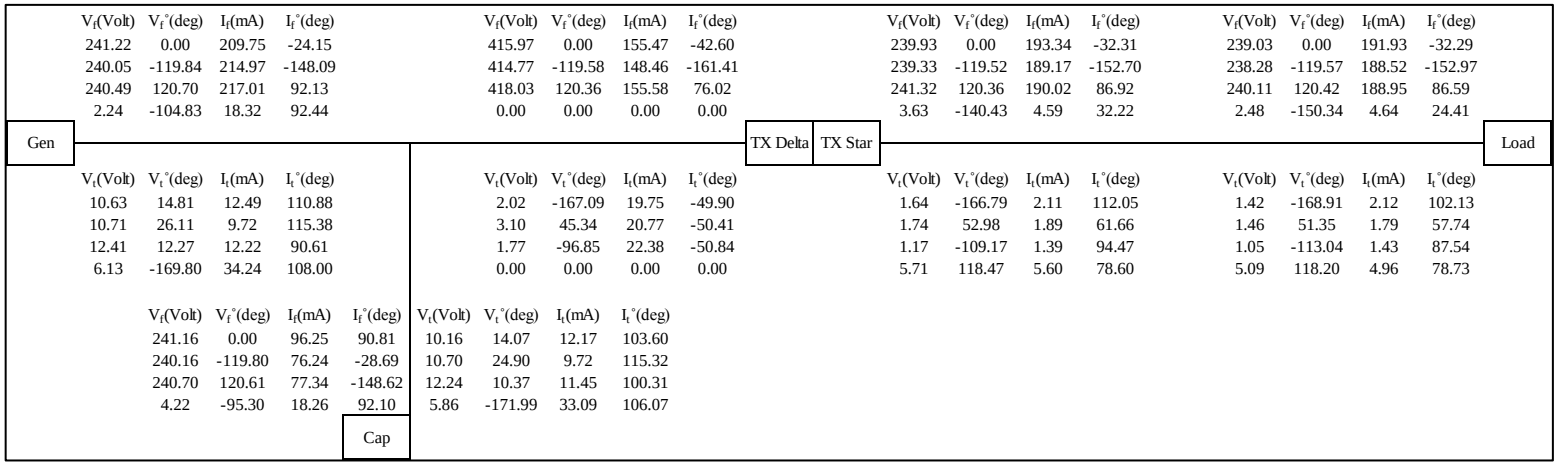


Figure 114: Measurement for load 960Ω+j358 (1uF+0.22uF)

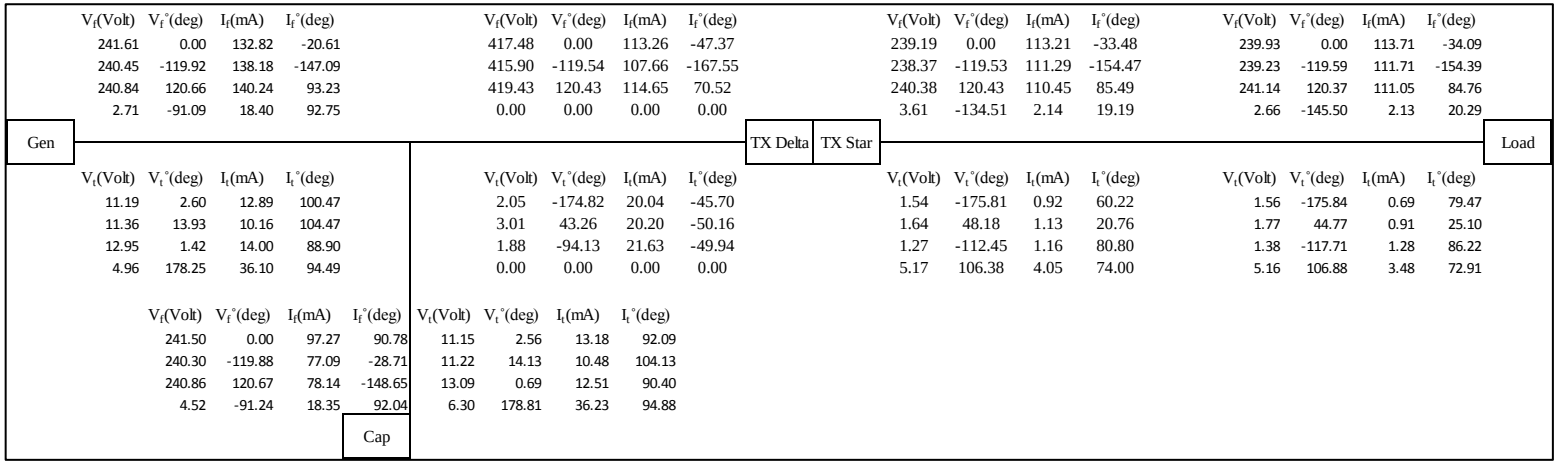


Figure 115: Measurement for load 1600Ω+j1194 (1uF+0.22uF)

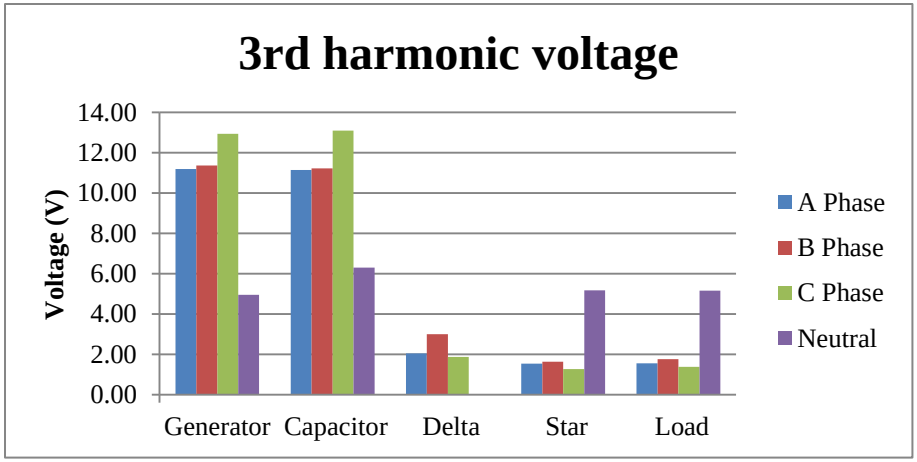


Figure 116: Third harmonic voltage for load 1600Ω+j1194 (1uF+0.22uF)

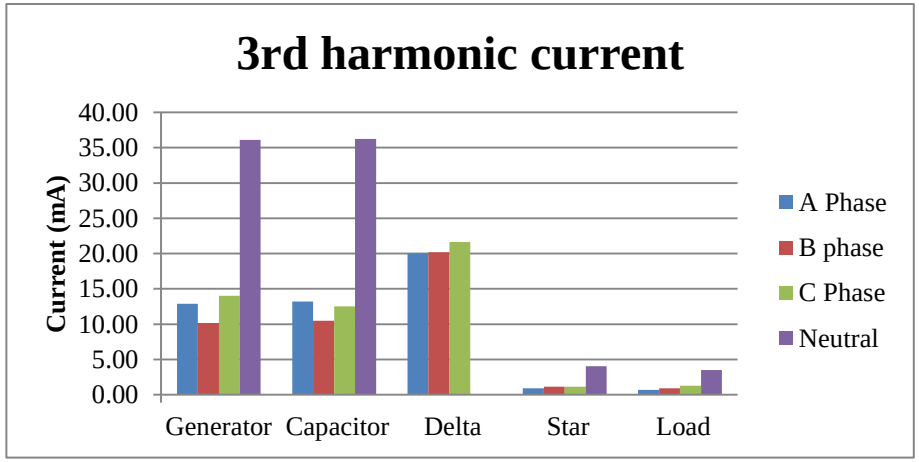


Figure 117: Third harmonic current for load 1600Ω+j1194 (1uF+0.22uF)

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
240.63	0.00	103.19	-13.61
239.60	-119.83	105.95	-141.95
240.10	120.64	108.69	98.75
3.15	-97.03	18.33	92.76

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
11.13	-0.93	13.33	98.17
11.39	11.64	9.98	102.41
13.27	-3.35	13.78	83.96
7.41	174.74	36.47	90.77

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
241.66	0.00	97.21	90.83
240.59	-119.83	77.03	-28.66
241.08	120.70	78.13	-148.62
3.82	-106.33	18.31	92.57

Cap

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
11.31	-1.65	13.36	88.48
11.24	10.83	10.47	100.87
13.10	-3.20	12.51	86.33
6.20	175.17	36.45	91.31

Gen

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
416.85	0.00	93.15	-48.70
415.47	-119.57	87.71	-167.86
418.76	120.38	94.51	69.49
0.00	0.00	0.00	0.00

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
2.25	-176.24	21.05	-46.42
3.38	34.12	20.58	-48.06
1.84	-107.64	22.12	-48.99
0.00	0.00	0.00	0.00

TX Delta

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
239.68	0.00	79.54	-29.36
238.96	-119.56	77.75	-150.03
240.98	120.37	77.81	90.43
3.04	-138.99	1.11	51.93

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
1.68	-175.87	0.88	155.21
1.82	39.39	0.31	102.79
1.26	-121.40	0.44	128.31
5.54	104.83	2.66	97.15

TX Star

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
239.62	0.00	79.65	-30.43
238.75	-119.48	77.76	-150.04
240.91	120.41	77.91	89.42
3.46	-134.03	1.17	40.63

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
1.91	-168.33	0.68	66.45
2.06	44.89	0.66	40.07
1.22	-115.98	0.54	153.51
5.28	103.74	1.49	106.15

Load

Figure 118: Measurement for load 2400Ω+j1602 (1uF+0.22uF)

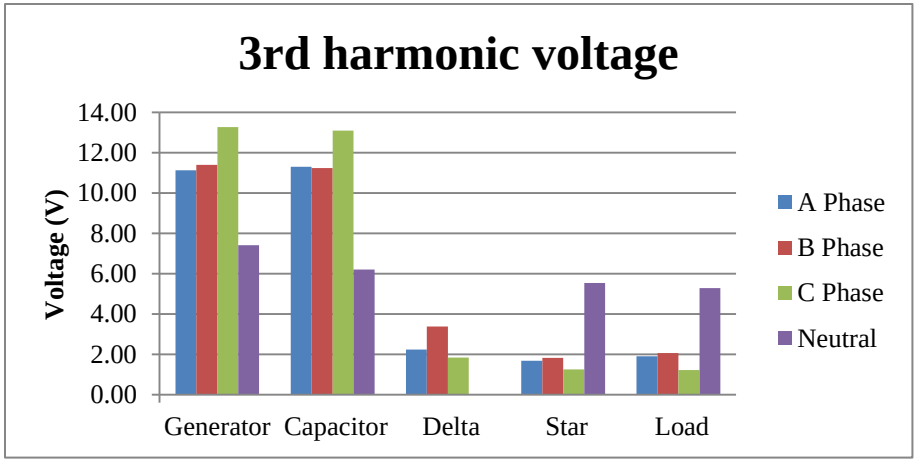


Figure 119: Third harmonic voltage for load 2400Ω+j1602 (1uF+0.22uF)

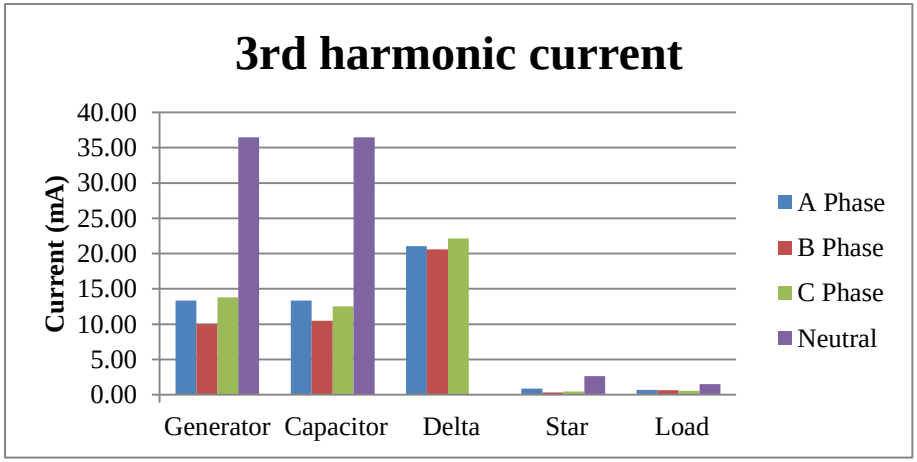


Figure 120: Third harmonic current for load 2400Ω+j1602 (1uF+0.22uF)

Vf(Volt)	Vf'(deg)	If(mA)	If'(deg)
241.33	0.00	80.66	-11.09
240.12	-119.85	83.45	-141.60
240.52	120.73	86.27	99.60
2.58	-88.57	18.16	91.77

Vf(Volt)	Vf'(deg)	If(mA)	If'(deg)
415.72	0.00	77.10	-51.95
414.35	-119.56	72.79	-172.30
417.62	120.39	78.51	67.10
0.00	0.00	0.00	0.00

Vf(Volt)	Vf'(deg)	If(mA)	If'(deg)
239.30	0.00	53.52	-30.31
238.61	-119.53	51.95	-149.38
240.63	120.36	51.71	89.58
2.75	-134.37	1.48	8.40

Vf(Volt)	Vf'(deg)	If(mA)	If'(deg)
239.89	0.00	53.64	-29.04
239.17	-119.56	51.97	-149.03
241.18	120.38	51.72	90.76
4.01	-124.66	1.45	-1.49

Gen | TX Delta | TX Star | Load

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
11.44	-6.21	13.08	92.79
11.12	4.98	9.85	95.85
13.37	-7.03	14.05	81.61
6.14	169.03	36.65	85.49

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
2.48	-178.89	19.98	-48.59
3.60	32.75	19.61	-53.19
1.97	-105.89	21.43	-52.70
0.00	0.00	0.00	0.00

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
1.89	-178.63	0.61	46.58
1.92	36.74	0.48	-6.78
1.27	-117.83	0.34	149.16
5.20	98.55	0.76	112.36

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
1.70	-179.31	0.95	134.95
1.77	36.99	0.24	107.37
1.27	-120.92	0.41	110.47
5.20	99.40	1.39	99.30

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
241.74	0.00	97.07	90.80
240.61	-119.89	76.95	-28.70
241.02	120.67	78.07	-148.66
4.69	-95.77	18.27	92.54

Cap

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
11.50	-5.64	13.58	84.18
11.46	5.33	10.64	95.82
13.33	-7.32	12.73	82.07
6.14	169.52	36.94	86.98

Figure 121: Measurement for load 3600Ω+j2388 (1uF+0.22uF)

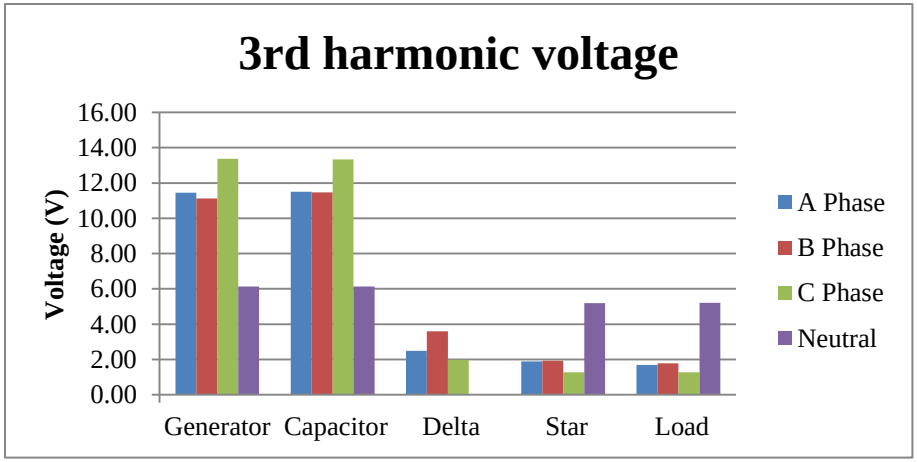


Figure 122: Third harmonic voltage for load 3600Ω+j2388 (1uF+0.22uF)

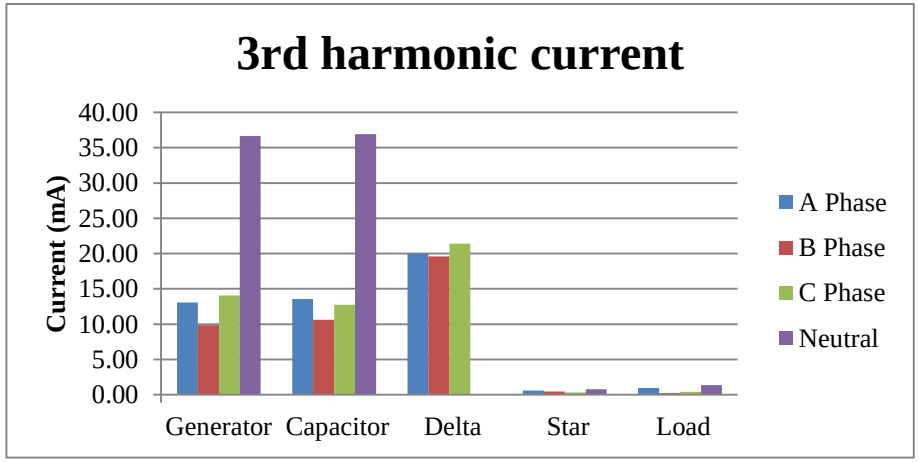


Figure 123: Third harmonic current for load 3600Ω+j2388 (1uF+0.22uF)

Vf(Volt)	Vf'(deg)	If(mA)	If'(deg)
240.94	0.00	65.65	-7.68
239.86	-119.78	67.50	-140.65
240.41	120.67	71.00	100.79
2.52	-96.87	18.15	92.38

Vf(Volt)	Vf'(deg)	If(mA)	If'(deg)
419.33	0.00	71.79	-55.82
418.13	-119.64	67.75	-176.28
421.08	120.37	73.60	63.41
0.00	0.00	0.00	0.00

Vf(Volt)	Vf'(deg)	If(mA)	If'(deg)
240.31	0.00	38.30	-32.69
239.54	-119.51	37.56	-152.00
241.59	120.39	37.01	87.66
4.46	-122.30	0.34	-4.22

Vf(Volt)	Vf'(deg)	If(mA)	If'(deg)
240.70	0.00	38.47	-33.25
240.06	-119.58	37.67	-151.60
241.91	120.31	37.29	86.86
4.33	-122.80	0.34	7.07

Gen | TX Delta | TX Star | Load

V_t(Volt)	V_t'(deg)	I_t(mA)	I_t'(deg)
11.53	-9.67	13.50	86.99
11.63	3.30	9.92	88.44
13.52	-10.33	14.62	71.99
6.11	166.37	36.61	84.68

V_t(Volt)	V_t'(deg)	I_t(mA)	I_t'(deg)
2.16	177.00	20.97	-46.71
3.45	25.76	20.10	-51.86
1.94	-120.33	21.95	-51.26
0.00	0.00	0.00	0.00

V_t(Volt)	V_t'(deg)	I_t(mA)	I_t'(deg)
1.84	-175.24	0.48	-122.32
1.89	37.98	0.34	-94.60
1.19	-120.00	0.14	119.86
5.10	95.52	0.52	95.18

V_t(Volt)	V_t'(deg)	I_t(mA)	I_t'(deg)
1.93	173.77	0.62	23.21
1.88	33.10	0.43	-25.89
1.45	-116.39	0.32	-178.51
5.17	94.39	0.34	109.55

V_f(Volt)	V_f'(deg)	I_f(mA)	I_f'(deg)
241.03	0.00	96.85	90.75
240.02	-119.91	76.74	-28.73
240.42	120.59	77.84	-148.66
4.56	-100.43	18.28	92.26

Cap

V_t(Volt)	V_t'(deg)	I_t(mA)	I_t'(deg)
11.67	-7.98	13.76	81.20
11.68	2.71	10.82	92.88
13.58	-11.06	12.93	79.37
6.14	165.56	37.21	84.08

Figure 124: Measurement for load 4800Ω+j3581 (1uF+0.22uF)

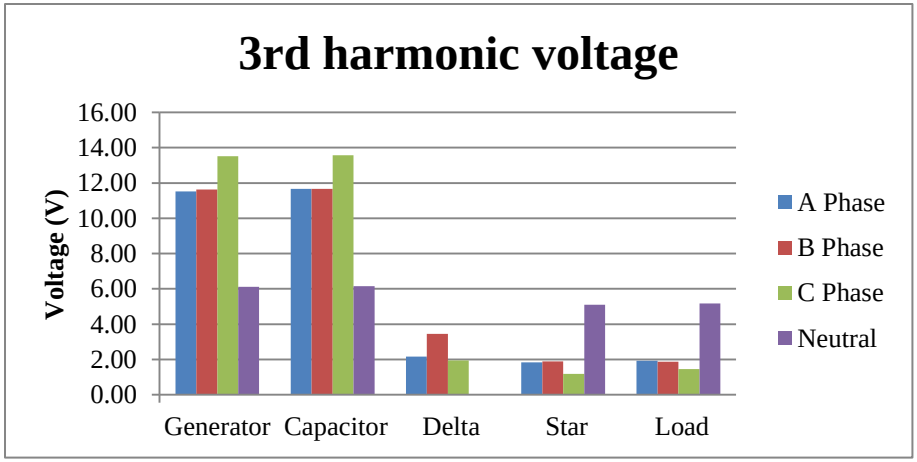


Figure 125: Third harmonic voltage for load 4800Ω+j3581 (1uF+0.22uF)

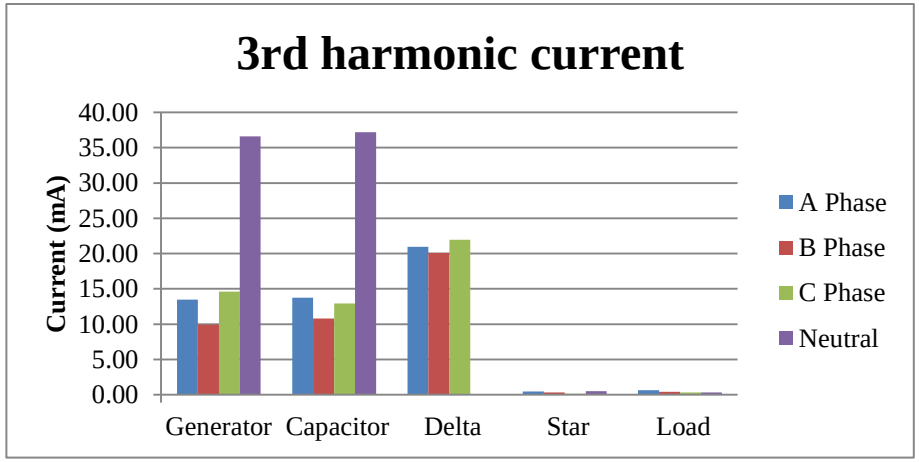


Figure 126: Third harmonic current for load 4800Ω+j3581 (1uF+0.22uF)

Appendix I: Generator Connected With Capacitor, Transformer and Load (1uF+0.55uF)

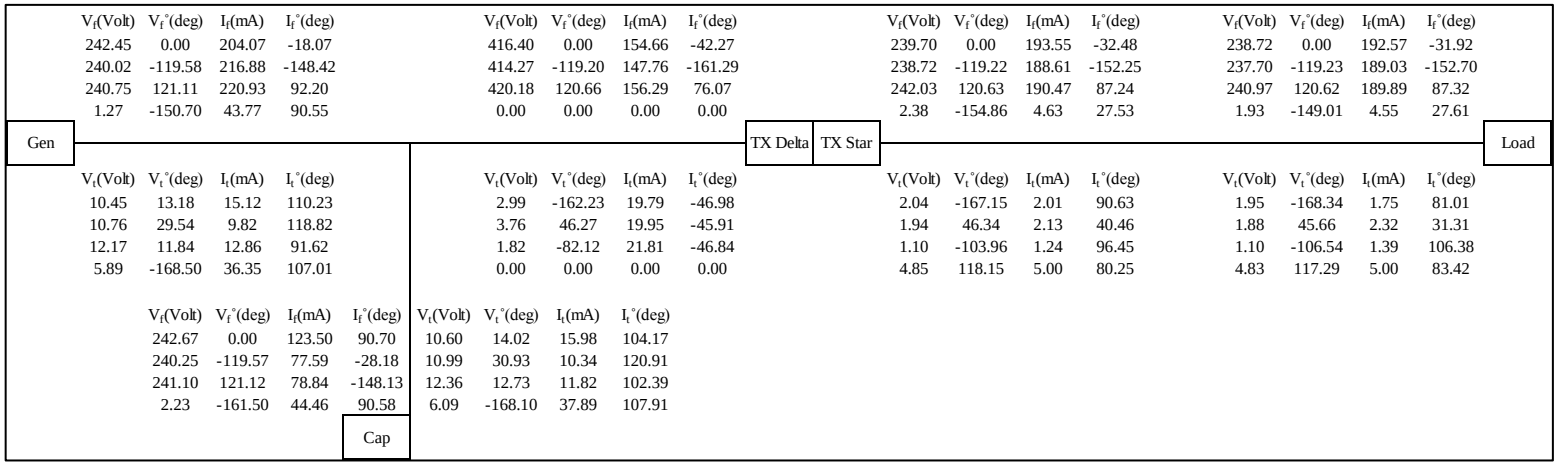


Figure 127: Measurement for load 960Ω+j660 (1uF+0.55uF)

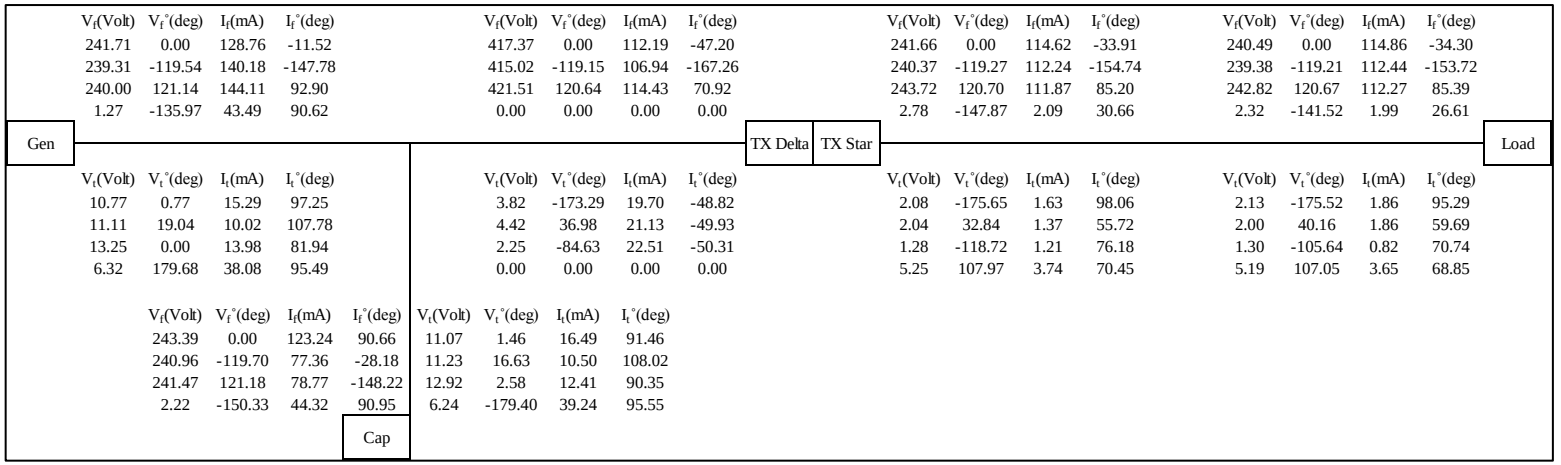


Figure 128: Measurement for load 1600Ω+j1194 (1uF+0.55uF)

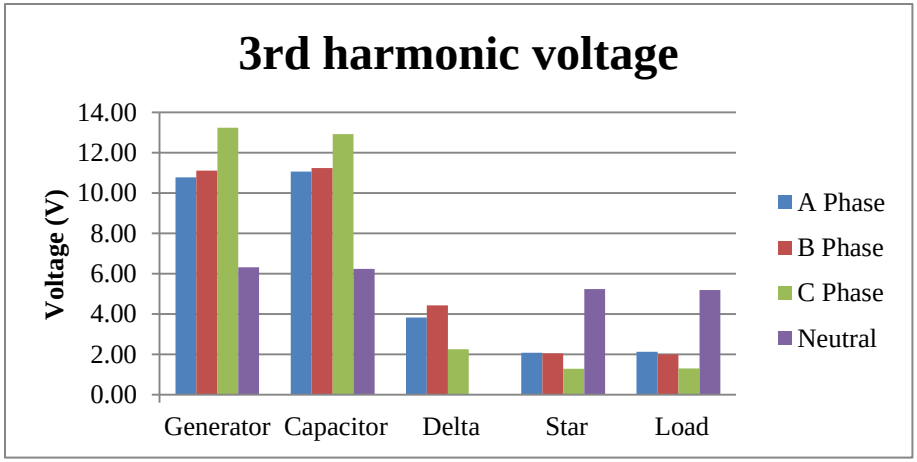


Figure 129: Third harmonic voltage for load 1600Ω+j1194 (1uF+0.55uF)

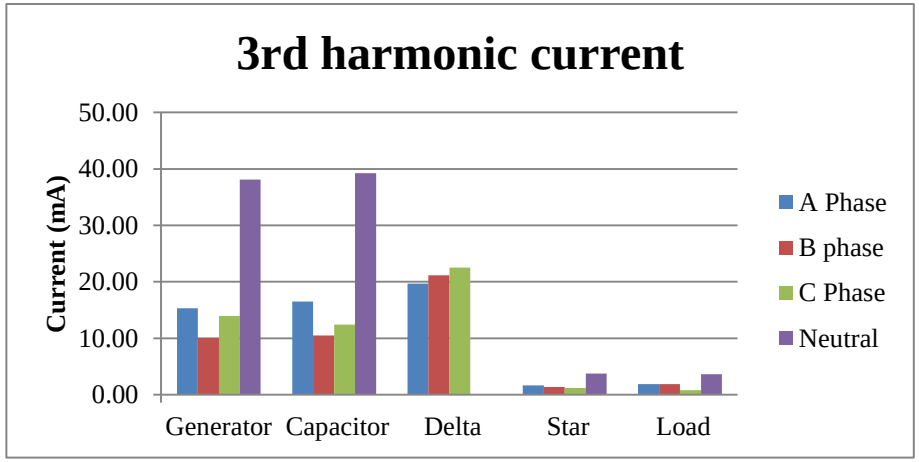


Figure 130: Third harmonic voltage for load 1600Ω+j1194 (1uF+0.55uF)

Gen

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
242.38	0.00	100.74	0.73
239.80	-119.63	105.52	-141.77
240.52	121.19	109.65	99.42
1.51	-119.77	44.07	90.34

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
11.28	-2.19	16.12	95.13
11.28	15.63	10.32	105.36
13.27	-2.33	14.59	82.10
6.06	176.14	39.74	91.93

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
242.40	0.00	123.00	90.64
240.05	-119.65	77.17	-28.21
240.68	121.10	78.52	-148.14
2.28	-138.74	44.25	90.80

Cap

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
11.23	-1.89	16.66	87.56
11.35	16.13	10.63	106.08
13.17	-3.30	12.69	86.90
6.29	177.14	39.89	92.35

TX Delta

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
415.12	0.00	91.51	-48.06
412.85	-119.28	87.05	-168.62
418.66	120.70	94.22	70.42
0.00	0.00	0.00	0.00

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
3.21	-176.71	20.95	-48.05
4.25	22.65	20.85	-48.05
1.85	-115.15	22.26	-48.24
0.00	0.00	0.00	0.00

TX Star

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
240.19	0.00	80.08	-30.77
239.03	-119.23	77.76	-149.63
242.39	120.65	78.33	89.97
2.85	-143.08	1.08	47.74

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
2.29	-177.65	1.24	128.66
2.38	32.77	0.83	96.66
1.44	-116.77	0.31	120.61
5.19	105.67	2.28	98.68

Load

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
239.39	0.00	79.91	-30.43
238.03	-119.17	78.17	-150.25
241.64	120.69	78.36	89.77
3.04	-138.23	1.01	44.79

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
2.39	-173.47	0.68	70.83
2.29	37.10	0.96	15.63
1.23	-108.21	0.60	155.53
6.03	104.35	1.58	104.47

Figure 131: Measurement for load 2400Ω+j1602 (1uF+0.55uF)

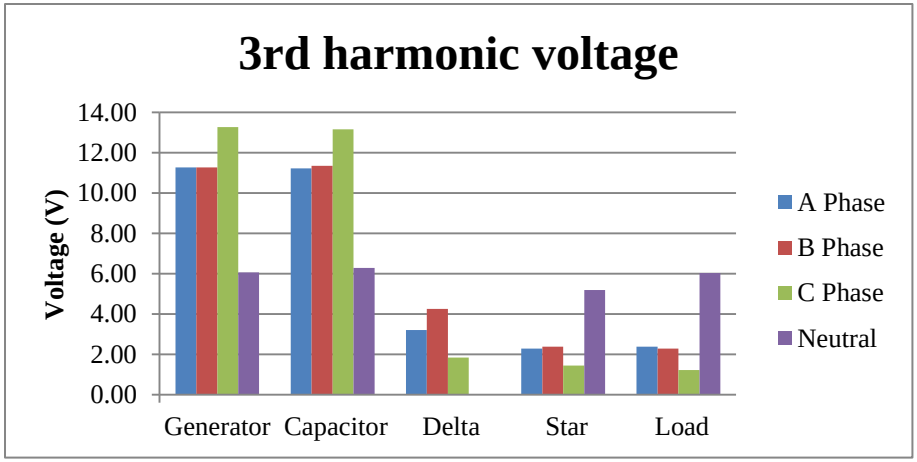


Figure 132: Third harmonic voltage for load 2400Ω+j1602 (1uF+0.55uF)

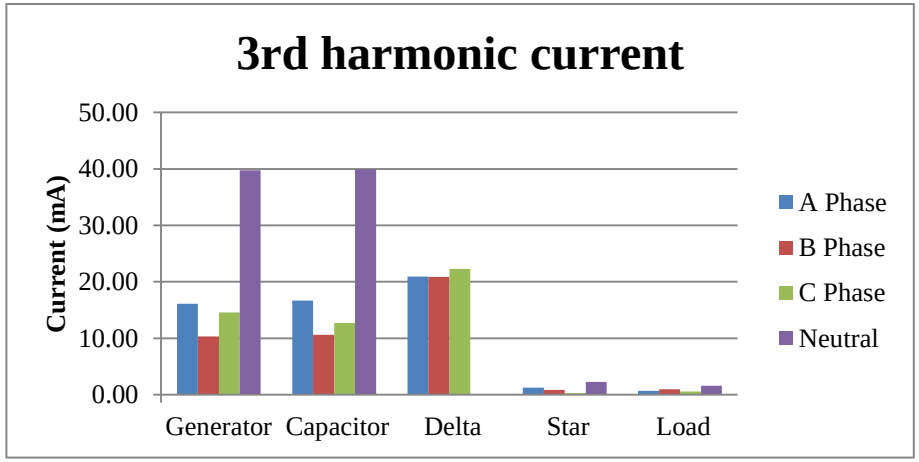


Figure 133: Third harmonic current for load 2400Ω+j1602 (1uF+0.55uF)

Vf(Volt)	Vf'(deg)	If(mA)	If'(deg)
242.37	0.00	80.17	6.10
239.95	-119.66	83.34	-141.60
240.55	121.12	87.79	99.53
1.60	-113.52	43.52	90.50

Vf(Volt)	Vf'(deg)	If(mA)	If'(deg)
416.04	0.00	77.27	-51.89
413.86	-119.24	72.01	-170.60
419.97	120.65	79.79	65.96
0.00	0.00	0.00	0.00

Vf(Volt)	Vf'(deg)	If(mA)	If'(deg)
241.35	0.00	54.24	-30.26
240.04	-119.26	52.63	-149.74
243.38	120.68	52.54	89.58
2.86	-139.40	1.35	8.12

Vf(Volt)	Vf'(deg)	If(mA)	If'(deg)
240.66	0.00	54.09	-30.01
239.44	-119.29	52.29	-148.20
242.76	120.65	52.19	90.84
2.75	-135.57	1.38	-3.21

Gen | TX Delta | TX Star | Load

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
11.24	-7.46	15.79	88.43
11.38	9.17	9.74	98.20
13.22	-7.37	14.97	76.08
5.99	170.94	38.89	86.77

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
3.56	177.90	20.20	-46.97
4.67	28.95	20.17	-49.04
2.48	-102.69	21.89	-49.01
0.00	0.00	0.00	0.00

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
2.19	179.47	0.37	16.20
2.13	28.83	0.62	-37.04
1.30	-120.42	0.51	153.88
5.05	98.73	0.90	107.98

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
2.25	178.35	0.55	48.29
2.38	29.68	0.88	-6.15
1.55	-121.04	0.51	170.20
5.06	99.32	0.87	102.99

V_f(Volt)	V_f°(deg)	I_f(mA)	I_f°(deg)
243.26	0.00	122.56	90.72
240.79	-119.58	76.97	-28.18
241.58	121.14	78.20	-148.09
3.13	-93.90	44.06	90.88

Cap

V_t(Volt)	V_t°(deg)	I_t(mA)	I_t°(deg)
11.14	-8.14	16.63	82.44
11.45	10.68	10.62	100.61
13.50	-7.35	12.82	82.09
6.13	170.59	39.43	87.21

Figure 134: Measurement for load 3600Ω+j2388 (1uF+0.55uF)

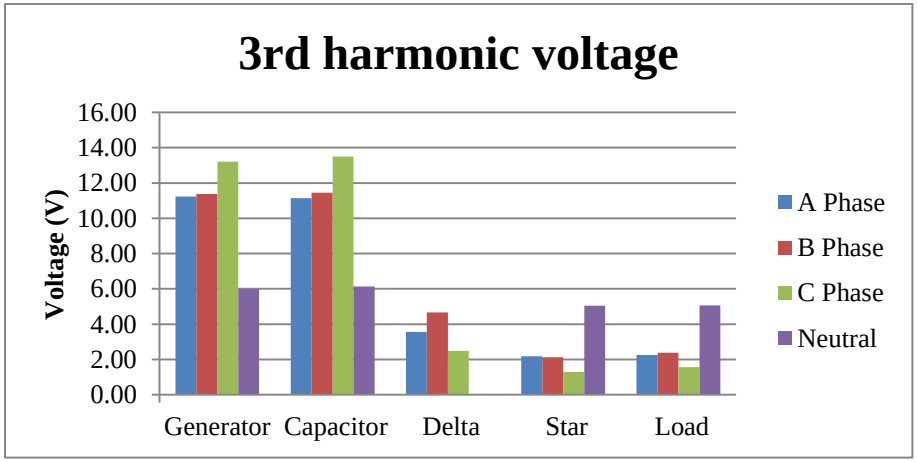


Figure 135: Third harmonic voltage for load 3600Ω+j2388 (1uF+0.55uF)

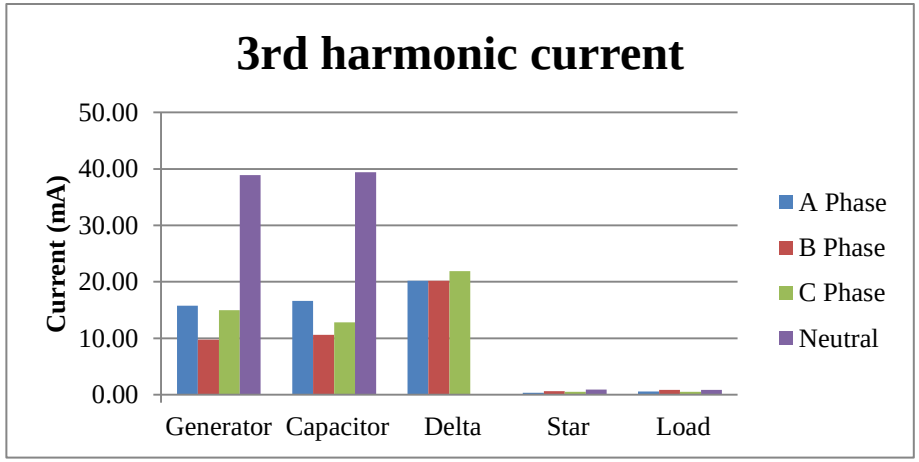


Figure 136: Third harmonic current for load 3600Ω+j2388 (1uF+0.55uF)

Vf(Volt)	Vf'(deg)	If(mA)	If'(deg)
241.82	0.00	67.06	14.92
239.47	-119.60	66.48	-139.66
240.22	121.09	71.36	101.74
1.65	-122.25	43.74	90.47

Vf(Volt)	Vf'(deg)	If(mA)	If'(deg)
415.45	0.00	69.20	-55.08
413.12	-119.18	64.44	-174.54
419.59	120.70	71.88	63.02
0.00	0.00	0.00	0.00

Vf(Volt)	Vf'(deg)	If(mA)	If'(deg)
238.49	0.00	38.25	-33.90
237.19	-119.16	37.18	-151.16
240.81	120.68	36.90	88.05
2.98	-143.49	0.19	-18.86

Vf(Volt)	Vf'(deg)	If(mA)	If'(deg)
239.24	0.00	38.27	-31.75
238.00	-119.19	37.87	-153.20
241.54	120.65	37.04	88.87
2.85	-141.16	0.20	-20.62

Gen | TX Delta | TX Star | Load

V_t(Volt)	V_t'(deg)	I_t(mA)	I_t'(deg)
11.16	-9.81	16.17	86.91
11.66	7.53	9.97	94.22
13.85	-10.45	15.39	77.04
5.74	167.31	40.15	83.97

V_t(Volt)	V_t'(deg)	I_t(mA)	I_t'(deg)
3.71	178.01	19.49	-48.01
4.49	27.18	19.79	-51.93
2.20	-97.46	21.63	-51.03
0.00	0.00	0.00	0.00

V_t(Volt)	V_t'(deg)	I_t(mA)	I_t'(deg)
2.55	177.68	0.74	139.64
2.41	29.30	0.49	131.44
1.40	-109.36	0.20	-3.22
5.07	97.79	1.24	87.49

V_t(Volt)	V_t'(deg)	I_t(mA)	I_t'(deg)
2.58	175.39	0.69	56.30
2.42	29.27	0.92	15.53
1.52	-108.49	0.37	-147.58
5.26	96.19	0.40	77.65

V_f(Volt)	V_f'(deg)	I_f(mA)	I_f'(deg)
242.93	0.00	123.89	90.57
240.50	-119.74	77.73	-28.25
241.01	121.12	79.16	-148.19
2.52	-142.20	44.54	90.82

Cap

V_t(Volt)	V_t'(deg)	I_t(mA)	I_t'(deg)
11.72	-9.38	17.37	80.56
11.82	7.64	10.98	97.97
13.50	-9.50	13.33	80.08
6.12	168.19	41.22	84.96

Figure 137: Measurement for load 4800Ω+j3581 (1uF+0.55uF)

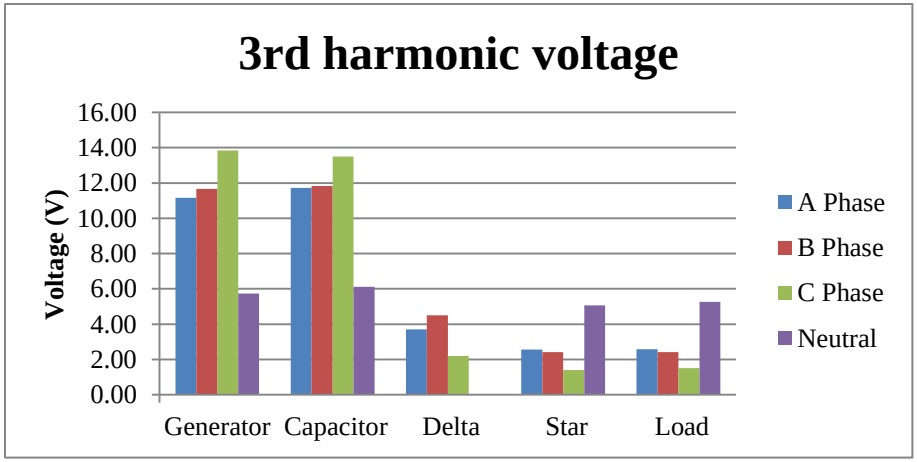


Figure 138: Third harmonic voltage for load 4800Ω+j3581 (1uF+0.55uF)

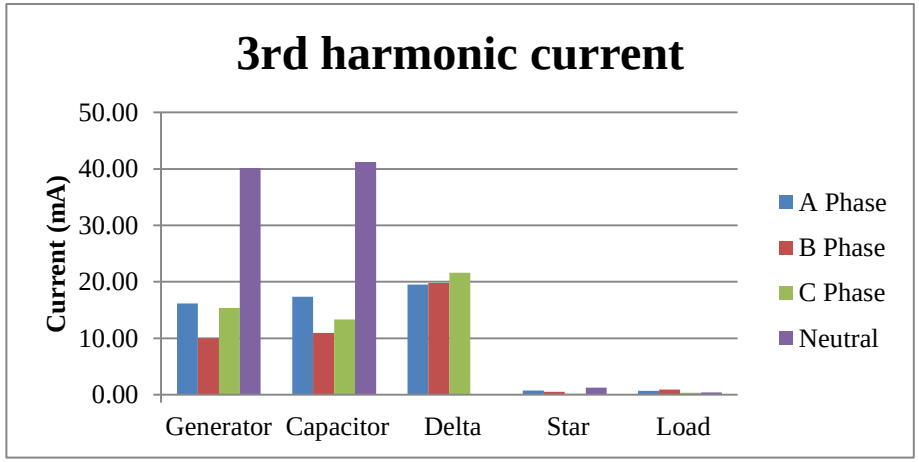


Figure 139: Third harmonic voltage for load 4800Ω+j3581 (1uF+0.55uF)